

THE TEACHING OF SCIENCE

By W. L. SUMNER

¶ The sections deal with science in girls' schools, practical science without laboratory accommodation, the 'manufacture' of apparatus, demonstration lessons, lesson notes and preparation, science libraries, etc. The book gives a survey of schemes of work and methods in general science teaching with special reference to Secondary Modern Schools under the 1944 act.

¶ 'Mr. Sumner has worked out an admirable course, with applications to almost everything that happens in the ordinary schoolchild's experience, from the national health insurance to the lighting of the school stage.'—

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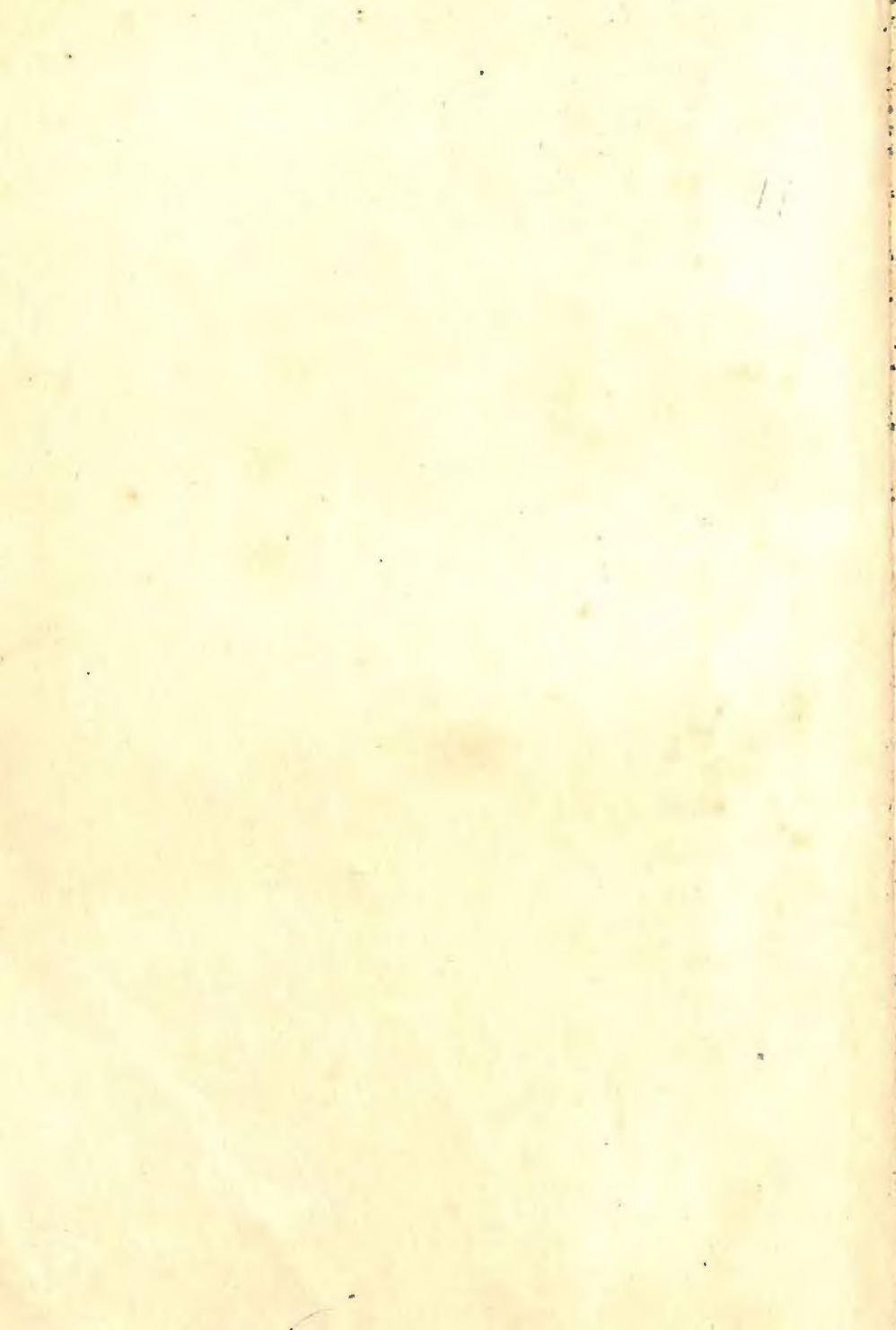
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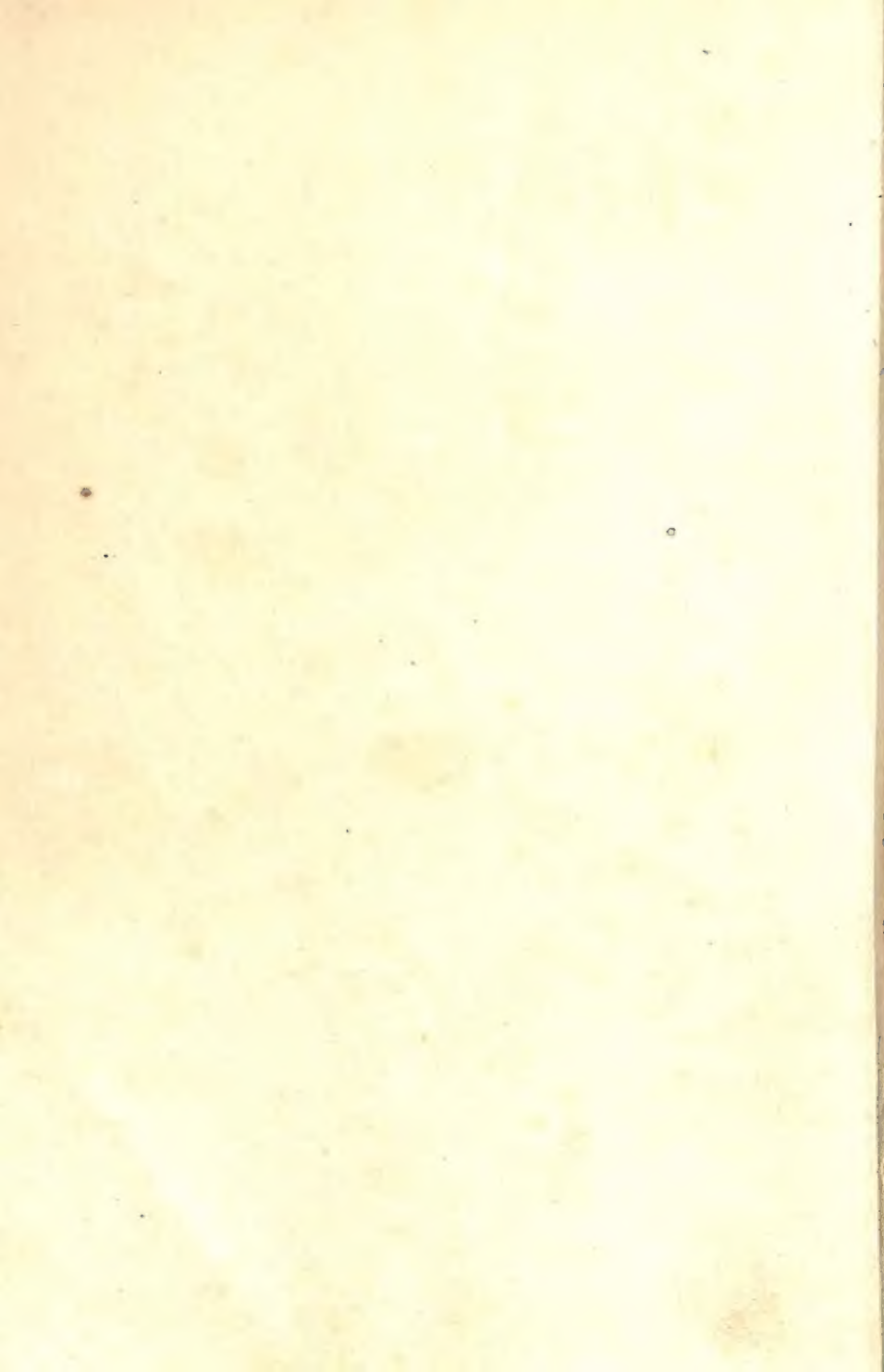


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OF
SCIENCE

By W. L. SUMNER

Senior Lecturer in Education at the University, Nottingham

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PREFACE TO THE SECOND EDITION

THE need for another edition of this book has given the author the welcome opportunity to make a number of corrections and additions and to bring the text up to date, in particular, with a view to possible post-war developments. The book was originally written with a twofold aim: firstly, to give a short survey of science teaching particularly in the post-primary schools, formerly known as modern, senior or central schools and now with the advent of the new Education Act as secondary schools and secondly, to provide a teacher's book for the four volumes of *An Introduction to Science* by Andrade and Huxley.

It is too early to distinguish between the work of the above types of school but the writer has suggested different schemes and methods of treatment of the subject matter for children of various attainments.

With regard to science work in grammar schools (which now include the former secondary and high schools) which was at one time a devitalized reflection of university teaching, it is pleasing to note that the treatment is growing more broad and humane. Also, one of the recent tendencies in adult education in its various forms, including education in H.M. forces, is the rising popularity of classes in General Science, from the standpoint of the applications of Science (e.g. Science in everyday life, in war and peace) and for the achievement of a better grasp of the modern world and its problems, through the medium of scientific thought and methods in biology, physics and chemistry with their interconnections and applications. No one can feel at home in the universe without a knowledge of the changes wrought by scientific discovery.

I am indebted to Mr. J. A. Lauwerys of the Institute of Education for some helpful suggestions, to Mr. Richard Palmer of the B.B.C. for some material used in school broadcast talks, to the British Film Institute for information concerning science films and to Miss M. D. Hickling for kindly checking the proofs.

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PREFACE TO THE FOURTH EDITION

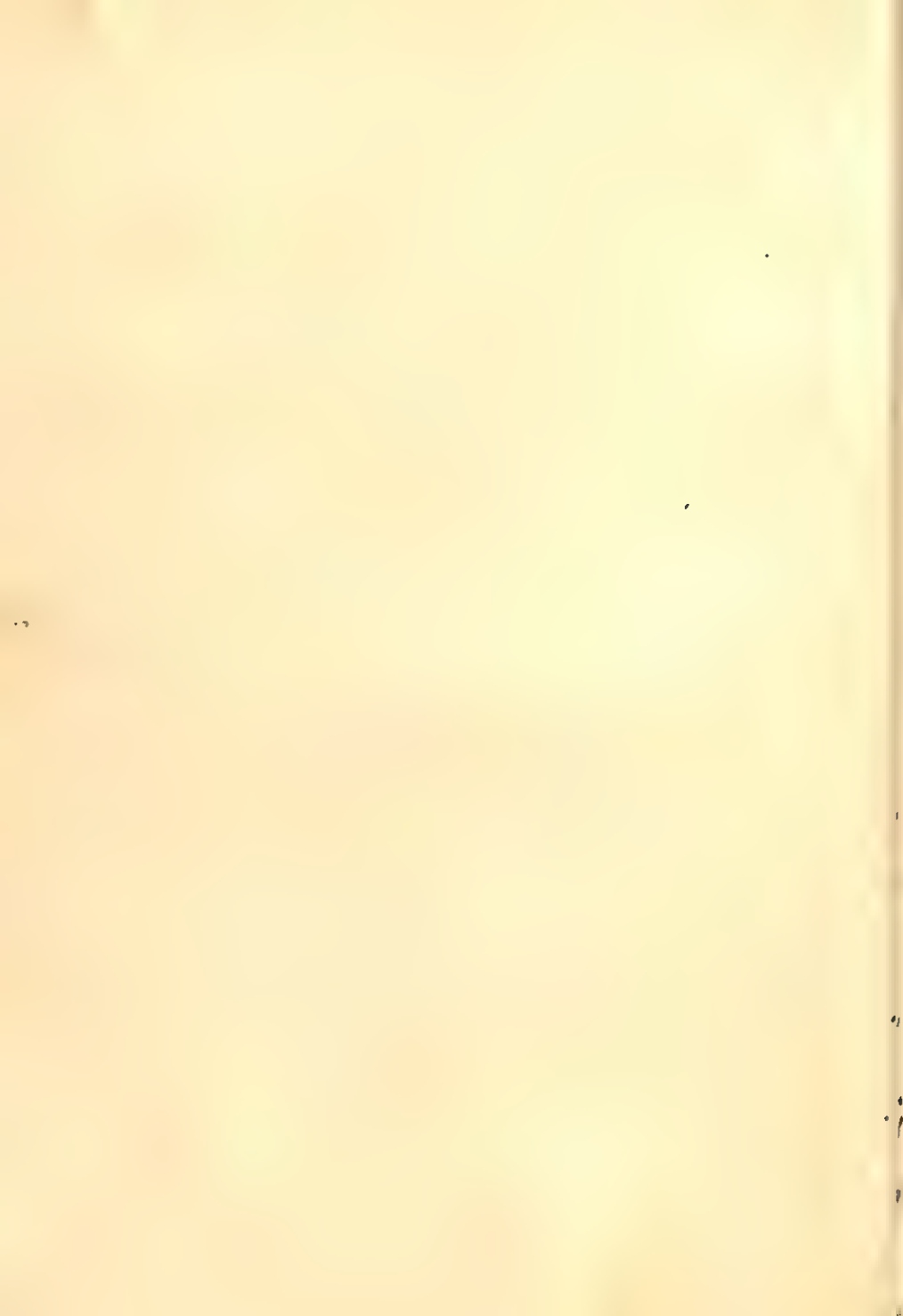
A number of additions have been made in this edition. The author has tried to bring the work up-to-date. In view of the present shortage of qualified Science Teachers particularly in secondary modern schools he has kept in mind the needs of the teacher who has no special qualifications in the subject. The book is intended for those who teach Science in secondary modern schools, but in view of the greater freedom in syllabuses in grammar schools it is hoped that it will not come amiss for the science work of all but the most senior forms of such schools. The author is indebted to his colleague Mr. N. C. Flower for some helpful suggestions.

September 1949

W. L. S.

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SCIENCE AS A SCHOOL SUBJECT

'That the natural knowledge which has been given to the world in such abundance during the last fifty years should remain untouched and that no sufficient attempt should be made to convey it to the young mind growing up and obtaining its views of these things is so strange that I find it difficult to understand; though I think I see the opposition breaking away it is yet a very hard one to overcome. That it ought to be overcome I have not the least doubt in the world.'

MICHAEL FARADAY in 1862 to the Public Schools Commissioners

'Science is *modern life itself* in one of its most fundamental aspects, and therefore an essential basis of a modern education for everybody. Not the whole basis by any means, but an essential part of the whole.'

SIR FRED CLARKE in *Education and Social Change*

WHAT are the claims of science as a school subject?

The school curriculum is full to overflowing and there are always reformers and enthusiasts who are anxious to insert yet another topic which 'provides an ideal mental training'. The teacher and scholar become bewildered, and sometimes the power of selection of really useful material is lost. Nevertheless, recent official publications show an understanding of the problems of both teacher and child, a desire for an elasticity of treatment and a humanity which is appreciated by teachers. Such freedom is given that much is left not only to the initiative of local authorities but to the teacher himself—and it is the teacher who should know his children, local conditions, and his own abilities, interests, and aspirations.

Our selection of material for teaching purposes and the methods employed are necessarily largely determined by our aims.

Formerly, the chief claim which was made for science was that it provided a unique training in careful experiment and observation, in making generalizations and framing systematic accounts of connected phenomena, in a patiently worked out and logical system of thought free from personal bias, and an account of the laws of causation and the methods of induction. To this can be added that Science is not hampered by tradition, its methods vary according to the problem in hand, it is dynamic, critical and gives opportunities for teamwork, discussion and clear description not encumbered with verbal quibbles.

No writer would deny the value of a scientific training and a scientific mode of thought, yet it is not so all-embracing in the field of knowledge as was formerly imagined and it can often be notoriously deficient in real interest and human values.

Few of the children we teach will become research scientists or university professors of science, but all of them will grow into citizens, who as a part of the State ought to take an interest in public well-being, the health and happiness of their fellows, and all will carry with them to the end of their days a living body obeying certain laws.

2- 'A knowledge of the facts and principles gained by scientific workers should result in a more rational mode of life; not only is such knowledge of benefit to the individual but to the community as a whole; for example, a well-instructed public opinion in matters of health should result in a healthier and therefore happier community.'¹ Bound up with this is the past neglect of biology and the dry irrational treatment of hygiene, which should have its roots in biology. Too often in the past it has consisted of the elements of physiology and a realization of the dangers of alcohol, and has had little connection with life and the well-being of the community and the individual. If no formal hygiene is taught in schools, constant reference to it may be made in the work in physics, chemistry, and biology. Much useful material is now available to provide a reasonable hygiene course. The Board of Education publication, *Suggestions on Health Education*, is extremely valuable, for it has a wide outlook and relates the subject to many branches of science and to history and geography. 'The proper study of mankind is man', and here we see in action individually and socially one of the most important aspects of that study.

The 'emotional' teaching of hygiene never did much good and sometimes was productive of a valetudinarian attitude which was at least as irritating in its own way as real physical disease. The great teacher, T. H. Huxley, fully realized the value and nature of scientific hygiene teaching. Indeed his whole attitude to science in education is worth studying (*Collected Essays*, Nos. 4 and 7), although, be it said, he was a voice crying in the wilderness, and the time was not yet ripe for the full application of his liberal ideas.

¹ B. of E. Pamphlet No. 89.

To him hygiene was just one aspect of a knowledge of the art of living, of realizing ourselves in Nature. 'The life, the fortune, and the happiness of every one of us and more or less of those who are connected with us depend upon our knowing something of the rules of a game infinitely more difficult and complicated than chess . . . The chessboard is the world, the pieces are the phenomena of the universe, the rules of the game are what we call the laws of nature. The player on the other side is hidden from us. We know that his play is always just and fair and patient. But also we know, to our cost, that he never overlooks a mistake or makes the smallest allowance for ignorance. To the man who plays well the highest stakes are paid with that sort of overflowing generosity with which the strong shows delight in strength. And one who plays ill is checkmated — without haste but without remorse. Well, what I mean by Education is learning the rules of that mighty game.'

Hygiene makes more than the personal appeal, for its social applications are amongst the most important of problems which true citizenship must face. One of the most curious and disappointing aspects of modern life is the complacency with which many accept disease, ill health and its concomitant misery, as though it were a part of the natural inheritance of man. ✓

3 One of the chief aims of the teacher of any subject should be to train the child to use his leisure to the best advantage both in his formative years and later in life. With shorter working hours and longer holidays this is ever becoming a more important problem, and the child should come into contact at school with a number of studies which may aid the development of strong sentiments in later years and form the basis of useful hobbies. Of course science is not alone in this matter, but probably subjects which are connected with science more or less directly form a greater number of 'after-hour' occupations than any others. The gardener will benefit both practically and from the gain in mental outlook which he will acquire, if he knows something of plant breeding, soil physics and chemistry, including scientific manuring and pestology. The real wireless enthusiast gains in his 'researches' if he has some knowledge of acoustics, 'capacity', and 'inductance' in electricity, while the amateur photographer, whether in black and white or colour, in 'stills' or 'moving pictures', will find that his results can-

not but help being improved by a study of optics and chemistry. One can multiply instances where hobbies which do not arise directly from the application of scientific principles are yet enlarged, improved, and rendered more pleasing by a knowledge of elementary science. The collectors of coins, stamps, books, as well as those of natural history specimens, often find a knowledge of chemistry an asset. Musicians, painters, sculptors are not ashamed to call in the aid of science, despite their assertions that art is above all these considerations; and books have been written giving a physical and mathematical treatment of the problems raised by rowing and golf!

That the hobby with a scientific basis is growing in popularity is shown by the ever-increasing number of semi-scientific periodicals which appear on our book-stalls. Locomotives, aeroplanes, steamships, wireless sets, television, photography, gardening, and hygiene all have their weekly periodicals; but there are others which deal with a much wider field such as *The Meccano Magazine*, *Work*, *Discovery*, *Hobbies*, *English Mechanics*, *The Model Engineer*, *The Scientific American*, to mention only a few, which often contain material which is at once practical, interesting, and very wide in its outlook.

Education does not end at fourteen or fifteen, and one of the weaknesses of the present system is that at this early age and at the dawn of adolescence with its disturbances and mental changes, the child may leave school to receive no more real attention to his bodily and mental welfare. A knowledge of elementary physical measurements and simple chemical changes will not help him much, under these circumstances. A satisfactory hobby, which may absorb a good deal of his time, thought, and activity may do much to help him to retain his equilibrium in later life.

Some knowledge of the present position and progress of science is necessary to obtain an adequate understanding of the world in which we live. Our mode of life has made us entirely dependent on the scientific discoveries of the last half century or so. So much depends on the applications of electricity that life would be paralysed without them. The stockbroker knows what happened in New York a minute or two previously and he can fix his prices accordingly; the motor car and 'bus' and the electric train enable the town worker to live in the suburbs away from his office. One

can ring up and converse by wireless-telephony with a friend or business associate in the Antipodes, or, alternatively, speak to a passenger on a liner in mid-Atlantic by merely talking into the telephone at home. With the development of the aeroplane one can breakfast in London, take tea in Africa, and return the same day. Our old conceptions of geographical distances and Britain's insularity are swept away by modern flying machines. The cinema, broadcasting, cheap books, and newspapers are all applications of science, and moreover, are still progressing towards a state which can hardly be predicted; and these are all forces which have to be counted in the lives of the people. No statesman, sociologist, or economist can afford to neglect them. History has already been made and changed by science. Every year shows fresh applications of physical and biological sciences to the problems of alleviating pain, curing disease, prolonging life, and the preservation of health. Short wireless waves are now added to the list of radiations of therapeutic value, and the treatment of certain diseases with the extracts of various endocrine glands and with the new drugs such as penicillin and the sulphonamides will sometimes produce results which seem miraculous. An ever widening knowledge of physiology is pointing the way to a more natural mode of life as regards diet, clothing, sunlight, and fresh air on the one hand; and an indication of possible developments in the art of healing on the other.

As we have seen to our sorrow the picture is not all bright, for the same coal tar which gives beautiful dyes, useful medicines, and disinfectants can also yield high explosives and irritant gases for the destruction of human life. The aeroplane, that quickest of all means of transport, can become the most terrible weapon of destruction, rendering armies powerless and obliterating for ever the centres of culture so laboriously constructed by man. In short, as he grows up the child should feel that he is becoming at home in a complex and changing world through his work in science.

Nobody ought to neglect this side of the subject. The utilitarian side of science is, comparatively speaking, so easily grasped and has grown up so quickly that the sense of moral responsibility with which it should be paralleled has been left far behind. The future can only be secure in the hands of a race of people who grasp the

significance of the changes which scientific discovery has wrought, and are fully alive to the responsibilities which have to be assumed for the heritage of the past. Science has simplified our tasks in the home, ensured us a varied supply of food throughout the year, enlarged our horizons when we travel, brought the world to our sitting-rooms, gone a long way towards eradicating pain and disease, provided cheap entertainment, and in a prodigal manner has scattered at our feet a wealth which kings could not purchase a century ago. Need it also prove the instrument of our destruction? ✓

The intellectual interest in scientific discovery for its own sake is worth fostering. Few children at school are sufficiently advanced to grasp even the fringe of the problems of the universe and man's place in it. Not many adults reach the stage of coming to grips with these ideas. Nevertheless, a desire to seek, to question, and to contemplate is latent in all intelligent beings. The seeds of a vigorous mental life may be sown at school and bear fruit later when the adult mind is enlarging its sphere of action and is trying to find even a partial answer to the riddles of the universe. When it became almost fashionable to read the popular astronomical books of Sir James Jeans many showed surprise and even wonder at the revelations found in their pages. Works of a similar type and subject, perhaps those of a generation ago, such as Ball's *Story of the Heavens*, were lying unopened on the library shelves. The child who in early years has peeped in at the keyhole of Nature will enlarge his field of vision when he grows up, and he will realize how one part of it dovetails with another; and in addition to the elements of the physical sciences which he may have learnt already, he will take up the studies of astronomy, biology, and psychology and try to work them into his own system of philosophy and apply the lessons learnt from their methods to the ordering of his own life.

However, one does not need to scan the heavens with enormous telescopes to find other worlds. The study of flowers, animals, birds, fish, and insects reveal fascinating worlds at our feet. The book of Nature whether of rocks, plants, or animals is one where there is always opportunity for much further simple research. Its laboratories are the fields, streams, woods, rocks, and the seashore.

For instance, how much can be learned from the study of insects, even without a microscope, valuable as is this.

Often the unexpected turns up, one piece of information leads to another and the quest taken up from the mere love of learning for its own sake may lead to a discovery which in its applications is of great service to mankind. Sometimes the 'scientific museum piece' of one generation is utilized in the realm of invention in the next. The discovery and preparation of 'heavy' water seemed at first to be of purely intellectual interest only, but the physiologist was quick to grasp that here at last was a means of solving the old and difficult problem of the absorption and excretion of water in the human body. The research of Sir O. W. Richardson and others on the emission of electricity from hot bodies appeared to be a fine piece of pure physics, but its later application to the thermionic valve helped to make modern wireless possible. On the other hand, the searches, perhaps neither systematic nor enlightened, for the Philosopher's Stone and the Elixir of Life left in their wake many genuine and useful discoveries.

The position of science as a subject rich in human values has often been denied. Some scientists of a decade or two ago have talked glibly about the 'Laws of Nature' and have tried to maintain that science shows in an objective manner what the Universe really is. These so-called 'Laws' are the product of the human mind just as much as is a work of art — they bear the imprint of the toil and thought of man and they are a reflection of what we can find of the Universe, from some of the best of intellects. The lives and methods of the great men of science are worth studying not only from the standpoint of biographical interest but because they show the living nature of the study of science and how it has developed, and instead of the false idea of an impersonal survey of the Universe delineated once and for all, one gains the conceptions of a vital growth with many a cul-de-sac preventing progress, with generalizations made tentatively, only to be cast away or qualified by later discoveries. The science student will acquire many skills and learn to adapt them to the task in hand. Most recent scientific discoveries have been made as the result of good team work (e.g. the methods of extracting penicillin by Professor Florey's group at Oxford).

The study of the applications of science and scientific method learnt at school will, it is hoped, pave the way for an appreciation of the problems of society in later life. Here we are on more difficult ground for everything seems to be in a state of change which many people accept as inevitable, and out of the sphere of human control. Also, in addition to the simpler ideas of physical cause and effect we have the more difficult problems of human motive and action, difficulties which are accentuated when, as in sociology, we have to deal with human beings *en masse*. Nevertheless, if modern civilized society is to persist and enjoy peace, health, and a full existence nationally and as individuals, it will only be attained through a fuller study of economics, sociology, and related subjects in a scientific way, and a determination to apply the results of such a survey. Poverty, disease of mind and body, the fear of war, and other evils still with us in our twentieth-century civilization need not be inevitable. Science is dynamic in that it is prepared to adapt its methods to the changes which are constantly taking place in the world. Changing social problems are to be solved by a vigorous and determined application of scientific methods rather than by political 'nostrums'. 'Unless science includes within its scope some consideration of human relations and interests', says Westaway, 'its priority of claim as an educational instrument will not remain uncontested.' The study of simple electro-magnetic phenomena gains by reading the life of Faraday. There is something of the Boy Scout ingenuity and resource in the thought of cutting up copper sheet into thin strips and insulating this with twisted paper in order to make covered wire, which to-day we buy so cheaply in reels. The works of the man often reflect the times in which he lived and the thought of his generation, and thus a useful correlation with history may result. For instance, Galileo is associated with the independent spirit of the new learning which was spreading through Europe, and the work of Lavoisier was thrown into relief by the French Revolution.

There is also the important but often forgotten moral aspect of scientific knowledge. Science is a legacy from the past and a gift from the present. Most people reap its benefits in the form of good sanitation, the myriad conveniences of electricity, wireless, painless surgery, and many other things, where they have not sown.

The guardianship of its uses and the formation of the correct scientific spirit must be a duty to the future.

Science is useful, though not unique, in that it provides practical material for the fuller and wider understanding of other academic subjects. Abstract mathematical calculations take on a new significance where it is shown that they really work out in practical experiment. Sir J. J. Thomson, the Cambridge physicist, was interested to see that Senior Wranglers, who represent the most brilliant of young mathematicians, were amazed to find that their formulae were true, when they did practical work in the laboratory!¹

Our aims in teaching should constantly keep in mind the need for providing a background or 'recognition' knowledge of a broad outline of the scientific field, together with a more detailed and even 'research' treatment of certain specialized topics.

There are many other aims and ideals of particular kinds which will be dealt with in further chapters, and in this introductory account of a general nature we do not propose to dwell on the direct or indirect application of science to studies of a purely vocational nature, though this aspect should be kept in mind. We live in a complex society which is sustained from day to day by the applications of science to our food, our health, the houses in which we live, our travels, our amusements. To maintain ourselves individually and nationally in such a world a continuous large supply of trained scientists and technologists is and will be necessary. All forms of Secondary education will have to make their contributions to this end.

The relations between science and other subjects are worth keeping in mind. Science cannot be taught in isolation and in the future the artificial division of the curriculum into subjects will have to give way to new integrations and a new conception of learning as a synthetic whole. Science and literature can be correlated in the five classics of scientific method which deal with original discoveries. The finest scientists usually had a gift of expressing themselves succinctly, clearly and in simple language in words. Excellent works such as Gilbert White's *Natural History of Selborne* rank high as literature, and *Madame Curie*,

¹ See Nunn, *Education: its Data and First Principles*, p. 188.

written by her daughter Eve, is an excellent biography. Good scientific description is a model of the correct use of words. Passages from original and historical scientific works¹ in modern languages other than English, should be used for reading and translation in the appropriate language lessons. Science has many connections with history, in fact, only when the scientific method was applied did history become a reliable study. History has shifted its focus from the stories of kings and battles to those of the people, how they lived, their ideas in relation to their environment. The people's lives are conditioned by the applications of science, which change their environment.

The science of history and the history of science cannot fail to find extremely useful correlations in the story of man both as an individual and as a member of social groups. Science is connected with the visual arts through colour, light and the optics of the eye, and with music through the nature of sound, its pitch, loudness and quality, the anatomy of the ear, the acoustical properties of musical instruments and of buildings. In the course of this book we shall mention some connections between 'domestic science' and science, and between craft work and science. In the latter case, the matter is more than the manufacture in the school of various pieces of scientific apparatus. The craftsman needs to know the properties of the materials which he is using, the composition and action of fluxes, the properties of metals, of plastic materials, of ceramics. There is a wide and important field here.

It is not necessary to say much here about the correlation between the scientific and mathematical subjects. It is one of absolute importance for mathematics is one of the chief languages, and sometimes the sole language of science. Graphs, equations, proportion, similar figures are constantly called for to interpret results and express scientific truths.

The problems of error, sampling and the use of simple statistical methods for arriving at a result within certain limits of accuracy are all useful considerations for teacher and student though at a somewhat higher level of attainment.²

¹ In preparation, 'A Documentary History of Science', by the present author.

² These matters have been discussed in a companion volume by the author, *The Teaching of Arithmetic and Elementary Mathematics* and in his *Statistics in School*.

Geography is replete with the applications of science. Physical geography deals with many problems concerning heat, humidity, air composition and pressure, and meteorology requires the use of barometers, thermometers, rain-gauges, hygrometers and other instruments. Geology is a near relation of geography, and studies of flora and fauna with particular reference to man and his needs are important in geographical studies.

At all levels science teaching has suffered in the past because it has been almost entirely absorbed by the factual and technical aspects of the subject. It has been possible for students to take good Honours degrees in certain branches of science and at the same time remain quite ignorant of the elementary principles of other science subjects, know nothing of the validity and limitations of scientific method under different circumstances and how even their particular branch of science grew up. These are serious shortcomings, and in these matters a number of Universities are by no means guiltless. The methods which a scientist or a team of workers may use to tackle a problem are more interesting in the wider field of education than the actual results which are obtained. The growth of scientific knowledge considered as history throughout the centuries should be of great value to the science teacher because his subject is here revealed as a human endeavour in its temporal and historical context. Moreover, the historical approach to a scientific topic is often the most logical and useful way of introducing it in class, and moreover it will go far to prevent the subject from degenerating into a series of isolated topics having little apparent connection with one another.

The disciplines of good laboratory work, the conduct of experiments, the making of observations and the recording and assessment of results must be regarded as an important part of all science work and if it is conducted properly it should give the pupil some idea of the manner in which scientists work.

Too much must not be expected of science. It is an excellent means of describing phenomena in the material world and hence it often provides clues to the control and exploitation of the physical and biological forces in the world. Science knows little of beginnings and ends, its methods of description are at the best partial and are entirely man made. The external world is only

knowable in terms of man's limited senses and mind. In the end models, pictures and words fail to serve for a good description of the ultimate forces and particles of Nature and man has to leave his generalizations locked up in mathematical equations. The strength of science is its unswerving and fearless search for the truth. At its best its high ideals and purity of purpose are its chief features. Only a degraded and contaminated science not worthy of the name can be conditioned by its contact with political systems and ideologies. What is scientifically true in England cannot be otherwise in New York or in Moscow.

Science does not give a complete description of natural phenomena but it deals with matters at various levels. For instance, in making an estimate of the density of a piece of metal it is not necessary to think of its possible biological significance, nor of the behaviour of the electrical charges which compose its atoms.

Scientific descriptions in terms of wave-lengths are inadequate when we deal with the visual beauty of a work of art or the aural beauty of a Beethoven Symphony. The ideas of poets, humanists, artists, religious thinkers and others whose thought is so important to the existence and ultimate well-being of man are not normally expressible in scientific terms. But that does not invalidate them. The orectic effect of Keats's poem

St. Agnes' Eve — Ah, bitter chill it was!
The owl, for all his feathers, was a-cold

is far more powerful than a mere expression of a number of degrees Fahrenheit below zero. There can be no clash between true religion and true science. In his day St. Thomas Aquinas was able to perform a remarkable synthesis of all knowledge, but as the centuries passed the vast increase of this produced more and more separation of the 'subjects' and further sub-divisions. A new synthesis is required which will relate our knowledge of the material world with human and spiritual experiences. Science has shown us how we may make our lives richer and fuller by the proper use of technical developments, it has shown us the uniqueness of man and his individuality; and through science we may see the work of God in the Universe. Thus science, when it is regarded as a part of man's heritage, is complementary to true religion.

The strength and the limitations of science have been succinctly stated by Dr. Sherwood Taylor in his fine book *Science, Past and Present* in the following words:

‘Science gives an intelligible picture of what we perceive by sense in so far as it can be expressed in terms of numbers, ratios, sizes, shapes, weights and motions and all the qualities and units derived from these. Thus, science sums up in a rational way a great part of our relation with the external world. Some would say it sums up or could sum up all of it, but this seems to be quite unjustifiable. So the scientific view of the world is a way of relating ourselves to it, and we enlarge ourselves by relating ourselves to the whole of the universe that man can observe and has observed by the methods of science. It also affords material for intellectual pleasure, wonder, joy and the perception of unity and design in that world. These are no part of science, but the knowledge of science may evoke them in the mind of man.

‘Furthermore, we can deduce from this provisional working-model of the universe that we call science, the best way in which to make the external world conform to our wills. Our wills are no part of science, and science cannot tell us what we *ought* to do: it can very often, however, tell us what will be the result of doing certain things. Thus when we have settled what we wish to do, science will tell us how to do it, and what will happen when we have done it, in so far as this is within the scope of that which science includes in its study. It cannot tell us how to sculpture a beautiful statue, for beauty is not a scientific conception, but it can tell us how to make an exact reproduction of an object, because this is a process concerned with one of the quantities (distance) that science studies. As regards actual projects, science may in the future show us how to move anything anywhere at any speed. It may enable us to make an unlimited variety of new materials, of every kind. It may enable us to modify our bodies and even our nervous organization to some extent, to cure or prevent all diseases, possibly to prolong life to an indefinite extent. It may so far increase the means of production of food, and of goods in general, that every man can have what he wants and do very little work to get it. It can increase our available stock of

knowledge indefinitely, but not complete it, for there will always be another question to ask. It can increase the individual's personal knowledge greatly by presenting great tracts of experience in the form of simple laws. It can also increase the powers of tyranny over man and abuse of nature to unthinkable limits, and has already afforded man the most gigantic power to destroy his fellows. Such are the powers of science.'

CHAPTER II

THE SPECIAL PROBLEMS ARISING IN SCIENCE TEACHING IN SECONDARY SCHOOLS¹

IN 1926, there appeared one of the most significant documents of the century in *The Education of the Adolescent* (The Hadow Report), which made recommendations for the re-organization of the education of children older than eleven. Central schools had grown up slowly since the early years of the century and for a number of years their special problems were overlooked and they tended, in their curricula and treatment, to take the lead from the Secondary Schools, very often emulating the very weaknesses of the latter. With the Fisher Act of 1918 the school age was raised to fourteen, with suggestions for yet another further year, and in 1944 the school leaving age was raised to fifteen and provision was made to provide suitable forms of secondary education for all children according to their ability. The majority of children do not go to a grammar school, but this does not mean that they are necessarily inferior to those who do. It is obvious that the young adolescent should not be regarded as an outgrown primary school child waiting until he is old enough to leave school; but special schools giving a completely organized scheme of work with his special needs in view should be provided.

Some form of post-primary education was to be planned for all children in accordance with their natural abilities. The scheme was to be mapped out as a whole, for a period of three or four years, and there was to be a realistic or practical tendency in the method of treatment. Of the many witnesses who gave evidence before the Hadow Committee it is interesting to note the opinions of employers on the subject of a vocational bias. Most of them stressed the value of science and mentioned the fact that although the course should not be limited by strict vocational demands, the teaching of science as well as of other subjects should give the child

¹ Using the nomenclature of the 1944 Education Act.

some ideas and inspiration for possible future tasks; and the school should be in a position to help him to choose his life's work and to indicate to him the necessary steps towards training for it.

'While the courses of instruction in modern schools', says the report, 'in the last two years should not be vocational the treatment of the subjects of the curriculum should be practical in its broadest sense and brought directly into relation with the facts of everyday life. The courses of instruction though not merely vocational or utilitarian should be used to connect the school work with the interest arising from the social and industrial environment of the pupil.' These remarks were intended to be general but they are particularly applicable to the subject of science.

'The aim of the modern school is to provide a good all round secondary education, not focussed primarily on traditional subjects of the school curriculum, but developing out of the interests of the children. Through its appeal to their interests it will stimulate their ability to learn and will teach them to pursue quality in thought, expression and craftsmanship. It will interpret the modern world to them and give them a preparation for life in the widest sense including a full use of leisure.' — Ministry of Education Pamphlet No. 9. The minimum course should be one of four years (for example, from the ages of eleven to fifteen) but it is evident that if double this period were available it would still be quite inadequate to do more than touch the fringe of the vast subject.

Instead of making an attempt to 'cram' the child with the outline of one or two physical sciences, it is far better to encourage enthusiasm for a general interest in science and to show the applications of science to the modern world. It is possible to do some excellent science teaching without a laboratory, indeed even without gas or electricity supplies. The finest research laboratories have no monopoly of the epoch-making discoveries, and the strongest science is not by any means confined to schools with the best and most expensive accommodation and equipment. There has arisen a 'tyranny of the laboratory' which is not in the best interests of science. It is a great convenience to have the very finest of apparatus, gas, water, and electricity at several voltages, but for simple work such as is done in most senior or central schools home-

made apparatus, an old car battery or two, etc., often serve the cause in a much better way, for a homely touch is given to the work, and a greater intellectual control of the principle involved results from experiments using the improvised apparatus. With the physical sciences in particular there grows up in the child's mind a feeling that the 'laws' of chemistry and physics only apply when proper flasks, test-tubes, Bunsen burners are used. Everything should be done to dispel this, though there is no reason to despise the proper 'tools' when one is fortunate enough to possess them; indeed, the care and maintenance of apparatus, and the best way of handling it, is as important in science as in the crafts. There is a story of Michael Faraday, which has some bearing on this point. He was due to lecture on frictional electricity at a small town some distance from London, but, unfortunately, his bulky apparatus of electrical machines, Leyden jars, and the usual collection of insulating stools, butterfly nets, and electrophori which were associated with this rather obsolescent branch of science were lost on the journey. Faraday was not daunted, but using materials which he borrowed from the chemist's shop, a cabinet maker's shed, and a public house in the district, he improvised sufficient apparatus to give his lecture and delighted the audience with magnificent sparks, brush discharges, electric shocks, and other phenomena. To my mind the lecture gained rather than lost in its effects, for it was one thing to bring 'boxes of magic' from London and another to show that the things of everyday life could be used for the purpose. One can imagine not a few of the country town enthusiasts rotating large empty glass bottles, rubbing them the while with various substances, and collecting the electricity with brass rods, after the visit of Faraday. This is the true spirit in early science work!

The next point we must raise is that it is impossible to find a course in science which will suit all children in post-primary schools. An ideal system would provide schools for every degree of intelligence and ability. Many of our secondary schools are not selective, indeed one sometimes finds a few children in each who would be better placed in special schools. In any case, even a tripartite division into A, B, and C classes for each age group will show great differences in the abilities and interests of the A and C

classes. With the latter it may be better to let all science teaching depend on simple handicrafts, gardening, hygiene and easy reading, using a concentric method; but in the former, one expects an intelligent outlook on the related phenomena of science, with initiative as shown in experiment and independent reading. In 'senior' schools, intended for those who are not sufficiently equipped mentally for 'grammar' schools, we have to adopt an even simpler and more practical outlook in the simple applications of science; whereas in the secondary modern schools work which includes formal science up to and above matriculation standard, though of a broader type, is not infrequently undertaken. Nevertheless, the fact remains that practically a new technique of science teaching is being built up for these schools. Such freedom is permissible that one might expect a multiplicity of schemes and methods of treatment, but in all schemes there are several desirable common points. In the first place a further dilution of the grammar school syllabus is definitely ruled out. More often than not, this was formerly characterized by the domination of examination syllabuses of a narrow and narrowing type. There was a vicious circle embodying university student, teacher and child, and the resulting conception of science was limited to a dry and simple edition of early university work in the physical sciences for boys, and in botany for girls. There was often too much laboratory work of a kind calculated to kill interest, a servile attention to time-honoured methods using standard and old-fashioned apparatus. It must be said, however, that from every side this vicious circle shows gradual but long overdue signs of breaking.

No regard was paid to the application of science to everyday things, despite the fact that each day saw another change in the world wrought by some scientific achievement; little attention was given to the creation of interest which would carry over to after-school life; there was little correlation between the various subjects in the domain of science, and still less with other studies; and there was usually a complete lack of humanism.

On the methods of teaching we shall touch in the next chapter, but in framing the syllabus the following points can be kept in mind.

1. Owing to the greater freedom with regard to examinations, in the 'modern' school the teacher can adjust the scheme to suit

the type of child, local conditions to a considerable extent, and his own personal attainments and enthusiasms.

2. In this type of school there are more opportunities for co-ordinating science, handicrafts, gardening, and other subjects. Simple pieces of apparatus should be made in the wood and metal workshops; and soils and manures, etc., can form the basis of applied science lessons in the garden.

3. As the 'modern' school course is usually shorter than that of the grammar school the work, though conceived as a whole and not as a mere filling in of three or four years, should endeavour to arouse enthusiasm for later reading or even serious study for its own sake.

4. On the whole, the type of child in the 'modern' school is less well fitted to receive an academic education than the grammar school pupil. Realistic, practical studies with adequate study of simple readable books on general science are indicated.

5. Provision should be made for science societies, visits to works and factories, and interest revealing itself in 'projects' and inquiries of the child's own.

6. The utilitarian and social aspects of science, such as gardening, domestic work, personal and social hygiene, should figure as developmental applications of the study.

7. The great importance of biology from every standpoint should be realized. The elements of descriptive botany and zoology do not satisfy the demands of such a broad and widely applied subject as biology.

Excessive specialization of science teachers in secondary schools is to be deplored, though many are finding a general honours degree and the broadening effect offered by a good post-graduate training year a useful equipment for commencing their tasks as teachers. It is pleasing to note that fourth-year physics and chemistry students, having obtained a degree, are taking up the study of biology and learning simple craft work in wood and metal. Other steps in the right direction are the study of astronomy, meteorology, physiology, horticulture, geology, etc., as 'interest' subjects. The physical sciences, despite the fact that they present only one aspect of the world of scientific thought, are of paramount importance as a basis for biological and other sciences. For

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instance, the physiologist finds that his work consists largely of applied physics and chemistry, and as the subject advances the two physical sciences seem to take on an ever-increasing importance. Without delicate electrical measuring instruments, thermocouples, cathode ray oscillographs, and amplifying valves, research on nerve currents would soon come to a standstill!

To return to the question of a science syllabus suitable for work in 'modern' schools, the Hadow Report makes the following suggestions, which if treated with thoroughness will serve as the basis for more than three years of work for the A classes. Indeed, in certain circumstances the scheme appears to be too ambitious, but normally it is excellent in that it provides a general survey of a very wide field, everything is susceptible to a simple treatment and to practical application, and moreover there is plenty of scope for expansion to suit the teacher and type of children.

(i) The chemical and physical properties of air, water, and some of the commoner elements and their compounds; the elements of meteorology and astronomy based on simple observations; and the extraction of metals from their ores.

(ii) A carefully graduated course of instruction in elementary physics and simple mechanics, abundantly illustrated by means of easy experiments in light, heat, sound, and the various methods for the production and application of electricity.

(iii) A broad outline of the fundamental principles of biology, describing the properties of living matter, including food, the processes of reproduction and respiration, methods of assimilation in plants, the action of bacterial organisms and the like.

(iv) Instruction in elementary physiology and hygiene based on lessons in biology. With the implementing of the 1944 Education Act and the raising of the school-leaving age another year is permitting a further extension of science work which might include a consideration of some problems of human biology, including a study of our behaviour (elementary psychology); various methods and modes of thought used in science, and the application of scientific principles to housing, health, resettlement and other important topical problems.

A great degree of co-operation between the teachers in various subjects in secondary schools should be looked for. The mathe-

mathematics teacher could relieve his science colleague of some of the fundamental operations in physics and chemistry calculations, and he will find that his own subject gains thereby. As is the case in an increasing number of these schools, the entire scheme of work in all subjects is known to every teacher and a system of mutual help evolves itself. The teacher of drawing can find materials in the biology, and even in the physics and chemistry courses, which will prove of value as an aid to both art and the sciences. The crafts master will find that the making of simple apparatus demands a knowledge of many practical processes, reveals a great deal about the use of wood and metal tools, and will call for operations which are not usually necessary in the ordinary run of cabinet making. A greater knowledge of the properties and fitness of certain materials for particular processes is required, and ingenuity and resourcefulness will be shown by adapting 'oddments' such as cigarette tins, small parts obtainable from the '6d. stores', various forms of cheap scrap, etc., to new and useful purposes.

Useful correlations can be made with geography, particularly physical and industrial geography, which will result in an increase in interest in both science and geography, will prevent overlapping and effect a saving of time.

METHODS IN GENERAL

SINCE the time of Newton this country has never been behind in supplying her share of great science workers, but usually their methods of approach were highly individualistic. Their results were communicated to select bodies, and until the latter half of the last century the idea of teaching science as a subject of interest and value to everybody had hardly been thought about. The distinguished amateur or patient observer with financial means to enable him to do his work, was the rule rather than the exception among men of science. Some workers, such as Cavendish, not only had no interest in using their discoveries for popular enlightenment but were reticent even in the matter of their publication. Sometimes, however, there were sporadic movements for popular lectures to adults such as those given by Davy at the Royal Institution. They bore fruit in the following generation through the enthusiasm which they inspired for science, but they did little to reveal that science could be made a useful teaching subject and less a subject suitable for schools. From the point of view of research the first sixty years of the nineteenth century was a great period in England. Magnetism, electricity, optics and heat were making great strides through the labours of such men as Davy, Faraday, Wheatstone, Wollaston, Tyndall, Maxwell, and their influence either through their immediate pupils or through their lectures must have been enormous. With the year 1851 came the Great Exhibition and German influence in science. In the popular mind the applications of simple physics and chemistry became almost a fashion and the spirit of that huge glass house with its 'science and art' persisted in South Kensington long after the 'Crystal Palace' was removed to Sydenham. It was seen that science could be applied most systematically not only to machinery but to mining, communications, and industry generally. Thomas Huxley was appointed to organize classes in science, and it is interesting to note that despite the fact that he was a biologist his own subject hardly figures in the lectures which his peripatetic

teachers went out to give. It has become the fashion to speak disdainfully of the work of Huxley and the Science and Art Department, but it must be borne in mind that he was a clear thinker with ideas on the aims of science teaching for which the time was not ripe. The physical sciences in their application had proved so useful and had captured the imagination of the public to such an extent, that there was little time for anything else. The utilitarian side of biology is more recent, for although the theories of Wallace and Darwin were read and widely discussed, the work of Mendel was not known until the end of the century and figures such as Pasteur and Lord Lister, the father of antiseptic surgery, who died in 1912, came later. The practical significance of applied biology was long in gaining recognition. The teachers from the Science and Art Department were usually content with a statement of facts often strengthened with a few simple experiments. Nevertheless, they met a real need and many of our greatest science teachers of a past generation obtained their first inspiration from these sources.

Towards 1890 came the inevitable reaction. Science, it was argued, was not a thing to be talked about, but a practical subject, knowledge of which could only be won by hard work in the laboratory. The correct way to learn is by doing, and the correct way to teach must ensure the use and development of the senses of touch and sight as well as of hearing. The true spirit of science is discovery, original investigation, an inductive method which experiments carefully and in due course draws conclusions. The pupil was to be put in the position of an original investigator and discover the principles for himself. Some adopted heuristic methods ('heurism' is derived from the Greek word for discovery) without examining them carefully, and others criticized in a short-sighted manner everything which Professor Armstrong, the sponsor of the scheme, had proposed. A more reasonable attitude would have saved much trouble; further violent 'swings of the pendulum' might have been prevented and a proper perspective obtained at a much earlier date than was actually the case. If, in the future, we can obtain greater freedom in planning the curriculum and arranging time tables we might be able to attempt something quite revolutionary by heuristic teamwork in or outside the laboratory. Both teamwork and individual activities may be envisaged in this

new conception of heurism. The work can be founded on the methods of the scientists themselves. 'Their procedure is very flexible, being adapted to the nature of the problems studied. Part of their activity is co-operative, part individual. Part of it is concerned with words and mathematical symbols and diagrams and part with materials and instruments. Their time is divided between the library, the study, the laboratory, and possibly the field, factory, mine, seashore, etc. They make mistakes, they follow blind trails and learn from these. They make notes, summaries, formulations, diagrams, graphs. They carry out exploratory experiments, measurement experiments, confirmatory experiments. They handle familiar concepts and create new ones. They deal with laws, formulae, hypotheses, theories. At convenient stages they record their findings in a paper.'¹

A laboratory, which after all is only a suitably equipped workshop, is a desirable convenience in any teaching institution claiming completeness, but a very useful course in science can be developed without a laboratory; and this state of affairs will at least prevent children from growing up to believe that science is only something to be done in a laboratory. After all, laboratories were made for science and not science for laboratories. Laboratory work is of exceptional value, but training in the use of tools and precision instruments can be performed equally well in a wood or metal workshop, and careful observation and note-taking can be done in the open air. One must admit a good deal of respect for the theoretical aims of heuristic methods, which indeed are often more useful elsewhere than in the laboratory. The teacher of science who works along heuristic lines with his pupils may find himself on the horns of a dilemma. Either he must be intellectually honest and cover such a little ground that the remotest idea of the dimensions of scientific thought and knowledge is lost, or else the pupil is in the false position of one knowing that he is not a discoverer in any sense and had full knowledge of the answer before he began. The quest had never been exciting and the experiments were neither fascinating to perform nor attractive in their results. All scientific inquiry should bring with it vigorous curiosity, and result in a feeling of satisfaction and joy. In the original account of

¹ Interim report of the Council for Curriculum Reform.

Boyle's discovery of his famous 'Law', by using an old barometer tube, we read how he called his wife into his workroom and stood in ecstasy for many minutes, admiring the apparatus and dwelling on the elegance of the result. Galileo in 1610 discovered the four great satellites of Jupiter 'with incredible jollity of mind'. Porta, one of the first to write about the formation of images with concave mirrors and convex lenses (*Natural Magick*, 1589) says with unmistakable enthusiasm, 'You shall see as it were the epitome of the whole world and you shall much rejoice to see it', and again, 'If you put a small lenticular crystal glass to the hole you shall presently see all things clearer, the countenances of men walking, the colours, garments, and all things as if you stood hard by . . . you shall see them with so much pleasure that those that see it can never admire it enough'; and one could go on multiplying instances.

The 'joy' and 'play' activities associated with the revelation of a new principle or application, whatever the medium through which the pupil obtains it, are necessary and get nearer to the true spirit of discovery than do long and tedious 'heuristic' methods which absorb so much time and usually yield so little in return.

The immediate effect of the heuristic 'craze' was unfortunate to the cause of science teaching in the Elementary Schools. The old object lessons, which with suitable treatment and arrangement might have developed into a most useful general science course, dropped out and were replaced by Nature study which was thought to be more susceptible to the methods of individual discovery; and physiography, a favourite topic of the early 'natural science' lessons, became a part of geography. Science demonstrations from 1890 onwards were 'regarded as positively harmful' and the few pieces of science apparatus formerly used were allowed to fall into disrepair or were broken up. In the early years of the present century there was a strong movement towards the co-ordination of handwork and science. By making his own apparatus, or at least seeing it made, the pupil obtained a better grasp of scientific phenomena and got to the essence of the principle involved. It was simple and cheap, it worked, it could be done at home as well as at school; the child's imagination was stimulated and it put him in touch with the larger feats of science and engineering. His

curiosity, creative and acquisitive instincts were obtaining satisfaction, and he was learning through hand and eye.

But with all this, the fact remains that the demonstration lesson in science is of such importance that nothing can take its place at present. It is the acid test of a good teacher, but when effectively done it saves time, enables a large field to be covered, is an excellent means of arousing enthusiasm, and, moreover, experiments of a more difficult character or those requiring highly specialized apparatus can only be performed at all as demonstrations. The matter will be treated more thoroughly in the following chapter. It must not be imagined that all 'heuristic' methods are to be condemned, but as we hope to show in the section dealing with practical and laboratory work special care is necessary in adopting them.

The present tendency in educational theory is to justify everything we do by the application of psychological principles, even perhaps when the results of this science are not sufficiently developed to give confidence that we are on safe ground in doing so. The psychological and biological theory of recapitulation suggests that the child in growing to manhood from birth (or even before this) develops in a way which can be described as a quick summary of the stages in the evolutionary history of man considered anthropologically. This principle has been widely and indiscriminately applied to education. The most we can say for it is that it may serve as a useful guide in an attempt to solve some of the riddles of the physical and mental development of the child, but it can become a very dangerous and perverse way of regarding a subject in which there is still room for a great deal of investigation. Despite all this, it follows that usually some useful parallelism can be determined between the manner in which knowledge was built up through the ages and the difficulties of a child in learning the subject, though this must only be considered along the broadest lines, as there have been periods like the 'dark-ages', when knowledge was merely latent or perverted.

Mr. Benchara Branford, in his *A Study in Mathematical Education*, compares the early development of mathematical conceptions, considered historically, with the child's widening outlook on the subject. In science there are three main stages, but it must be

remembered that each merges into the other gradually and should be added to it rather than be allowed to displace it. The three stages have been called those of (1) Wonder, (2) Utility, (3) Systematizing.¹ The young child's first reaction to the phenomena of Nature is one of wonder or awe. The counterpart of this is clearly seen in the behaviour of 'savage' tribes. Religion and 'science' are combined in functions of the 'medicine' man, and there is coupled with this an animistic tendency to read life into inanimate things. There is a god of the woods, another of the elements of fire and water, thunder is the voice of an enraged deity to be appeased by certain customs or offerings. Gradually, men came to apply logical reasonings to explain these rather terrifying natural phenomena. (We find Pliny, for instance, in a more civilized age, having the temerity to cast doubt whether 'thunderbolts' were really the 'wrath of Jove', for temples of the god, said he, suffered more than smaller structures in storms.) In the first stage the child shows the same animism, and projects his own personality into the phenomena of Nature; thus, we have Jack Frost, the Man in the Moon, and fairy rings and toadstools on the grass. This simple delight and wonder is the starting point of the study of Nature. It is inherent not only in childhood where it should be encouraged, but the tendency persists in adolescence. The popularity of works by J. M. Barrie, Kenneth Grahame, A. A. Milne, and of much mythology is largely due to the latent animism which is in all of us. Perhaps there are some stern realists who would despise any approach to science other than through strict experiment and induction, but to them we would say that animism is a first attempt at finding some ideas on causation and that not a few people have taken up serious Nature study after seeing *A Midsummer Night's Dream* or after reading Maeterlinck's book on the bee. The 'Wonder' stage merges into one where man is no longer overawed by the phenomena of Nature, but realizes that if he is careful he

¹ The late Professor A. N. Whitehead suggested: (1) Romance, (2) Precision, (3) Generalization. He also gave the following important warning.

'The romantic stage of language begins in infancy with the acquisition of speech, so that it passes early towards a stage of precision; while science is a late comer. Accordingly a precise inculcation of science at an early age wipes out initiative and interest and destroys any chance of the topic having any richness of content in the child's apprehension. Thus the romantic stage of science should persist for years after the precise study of language has commenced.'

can use it to his own ends. The delight and wonder, whether at the simple beauty of a yellow primrose or at the cataract of Niagara, should not be obliterated, but rather in addition man should seek a control, whether practical or intellectual, over the forces at work. Ancient man harnessed fire to cook his food, the wind to drive his ships even in an almost opposite direction, and the torrents of water to move his timber. The corresponding stage in childhood finds the boy or girl becoming curious to find out how things work. Scientific toys are popular because the child feels that he has control over mechanism. This is the age of the Hornby train, Meccano set, and box of chemicals. It is noticed more in boys than in girls, but it must not be imagined that girls have no interest in the more mechanical sides of science if they are given suitable opportunities. Probably the large majority of people never get beyond the wonder and utility stages in science work, but much useful work can be done without proceeding to the exercise of a still higher faculty.

Purely utilitarian control of simple natural phenomena sooner or later leads the better type of mind to extend its inquiries for the sake of the mental satisfaction which results. The desire to exercise intellectual control over Nature grows out of the simpler mechanical kind. The astronomer who is able to predict stellar phenomena feels that he has an intellectual control over what is happening — he endeavours to extend his inquiries for the pure love of knowledge and he hopes ultimately to have a system which in itself is a sort of control over the observations he has made. (Half a million pounds is joyfully spent in the production of ever bigger telescopes, but not because astronomers think that they will ever be able to obtain energy for commercial purposes from the incandescent stars, to colonize the planets, or to run a factory in the moon!)

In 'senior' schools the course is so short and the leaving age still so low that the great mental changes and the altered outlook on life which take place during adolescence have hardly begun. Actually, few children leaving grammar schools at the age of sixteen or eighteen have any really systematic knowledge of science as a whole. More often than not they go away with the elements of a pale reflection of a university course narrowed down to one or two branches of the whole field. Of course, in any school course,

however long, considerable limitations must be made, but the teacher who has inspired children to continue the inquiry and to enlarge their outlook will not have failed in his or her task.

It has been said that 'it is given to few to enjoy the cold austere beauty of the abstractions of higher mathematics', but although a larger number come to appreciate, even if not during school days, the elegant and comprehensive systems which have grown out of modern science, there still awaits the multitude which is capable of neither of these things and yet would find science in its simpler and practical results both useful and interesting.

In thinking of suitable methods of treatment the teacher should keep in mind these three stages of the growth of the subject in connection with the mental development of the child.

The good teacher will adapt his methods both to his class and to the subject which he has to teach. In the future we shall probably see more use being made of historical methods particularly for introducing science topics. Such methods will give a human turn to the work and at the same time will link it to other activities of mankind. In this, science teaching has been deficient in the past.

Historical material can be introduced in anecdotal fashion when required, or something of the lives of the great men of science may be given in appropriate lessons.¹ It need hardly be said that irrelevant details of a biographical nature are entirely out of place in science lessons.

The history of scientific method and the evolution of scientific thought in relation to contemporary ideas in other fields should be of great value in an attempt to weld the whole of simple scientific studies into a living, useful whole. Again, science may be considered historically in terms of the social changes which have been directly or indirectly effected by it. This is a more effective way with adults, but care should be taken not to infect the pure stream of science with political prejudice.

¹ The pictorial optical history in biographical form published by Bausch & Lomb (Rochester, N.Y., U.S.A.) is an excellent example.

THE SCIENCE LESSON—I

The Theoretical or Demonstration Lesson

It is probable that the lecture-table lesson will persist for a number of years as an important part of the school course. Wherever possible it should be used to supplement practical studies in science and in the future the 'theoretical' lesson will probably serve to co-ordinate the freer activities of an up-to-date 'heurism' effected by teams of workers. Here discussions of the methods and materials employed, the observations and inferences can be brought together and conclusions drawn. Here the lecture table as such will give way to the teacher's chair and he will act as a leader and friend. Some of the finest science work of the century has been done at the discussion groups and tea-parties of the late Lord Rutherford and Professor Niels Bohr.

When co-ordinated with visits to factories, film, film strip and lantern displays the lecture-table lesson has an important function in enriching 'background' and general science knowledge. It should never degenerate into a mere talk with demonstrations but class activity should always be provided in some form or other. A great lesson can be learnt from the Christmas lectures given at the Royal Institution each year to young people, when a distinguished scientist, academic in the highest degree, gives a series of lectures which hold the audience breathless, and moreover, not by having recourse to the more startling and rare manifestations of science, but by taking the common things around us, such as 'The World of Sound' or 'Old Trades and New Knowledge' — to quote two courses which have actually been given by the late Professor Wm. Bragg in recent years.

The science lessons both of students in training and young teachers often lose in effect for some of the following reasons:

1. The treatment is often extremely dull; far too frequently the lesson consists of the 'dry bones' of an academic course previously taken during the teacher's own student days. A breadth of treat-

ment is essential, the work should be applied to everyday experience, the practical achievements of scientific engineering, and the lives of the great scientists with whom the work was associated should be mentioned. Too often the teacher feels that simple apparatus is the only form of illustration about which he need trouble. Actually, he has as much need of pictures, whether in the form of book plates, posters, diagrams, lantern slides, or films as has the geography teacher.

To give an example — the latent heat of evaporation of water (latent heat of steam) is taught as a number of operations of routine weighings, a simple experiment, an equation of some complexity, and the matter is left at that. Useful applications of the principle such as the cooling of porous water vessels in hot countries or effect of the evaporation of perspiration on the human body are overlooked.

The science lesson which resolves itself into mathematical calculation loses something in interest for several reasons:

(a) The child may not have grasped that the position of science is strengthened when it is susceptible to a mathematical treatment. To him it is a weakness of science and not a strong point. He may have failed to see that from the gain both in intellectual and utilitarian control it is desirable to apply a yard-stick to the quantities which we have to deal with. Man in his attempt to understand the riddles of the Universe has felt himself to be on safer ground when he can give distances and times, for then he can predict events and check his results and theories by observation, and in the applications of science, it is of no more use trying to design an electric motor to drive a five-ton crane by a mere consideration of the qualitative aspects of electromagnetic induction than it is possible to make a box to given dimensions by just sawing up a tree trunk. Mathematics has done even more than this for science, for it has shown research workers where and how to look for their results.

(b) The child may not have yet attained in his mathematics lessons a sufficient grasp of the principles involved by some of the elementary experiments in science. Inverse proportion is necessary to understand the results of the ubiquitous 'Boyle's Law', and a knowledge of similar triangles and simple trigonometrical functions is needed for mechanics, optics, electricity, and magnetism. In

this the science teacher should endeavour to obtain the co-operation of his mathematics colleague. Mathematics becomes more real, living, and less abstract when applications are forthcoming. Much of what was contained in the former first year physics course could have been safely left to the mathematics teacher, not as an addition to his burden but as an extremely useful and desirable practical counterpart of simple mathematical principles.

(c) Frequently the numbers or quantities involved are merely learned in parrot fashion without an understanding of their real implication. Take for instance the number 537 (calories) which is used to represent the latent heat of evaporation of water. How does it compare with other quantities of heat, as for example the amount of heat required to raise the same weight of water from room temperature to boiling point? Figures soon get beyond what Sir John Adams used to call 'the threshold of stun' and then they mean nothing to the pupil. It is very easy to talk glibly about quantities but it is necessary to have some grasp of comparative magnitudes.

(d) Very often, the science problem which consists of a slavish and not very intelligent arithmetical working of a calculation (where little more has to be done than to fill certain given numbers in a remembered formula) has been made to stand instead of real thinking about vital matters. In the past, examinations have made this type of question possible, and sometimes both teacher and pupil have regarded it as a safe and 'soft' option. Fortunately, the 'secondary modern' schools are practically free from this tendency, which does great harm to the cause of true science.

2. The topics and the treatment chosen are often unsuitable for the type of child. As the matter of science lessons for various grades of children will be discussed later, we do not propose to say more now, but the methods used with an A form will naturally prove quite unsuccessful with C children.

3. Sometimes the lesson suffers because of insufficient preparation or general experience by the teacher. Attention to detail is necessary. Where apparatus is being used this should be carefully tested before the lesson begins. If there is time or opportunity, a rehearsal should be made. In the course of a fortnight the writer saw three lessons in schools far removed from one another, on the

topic of the pressure of the air. Water was boiled in a container, a cork or stopper was thrust in when the space above the water was deemed to be full of steam, and it was hoped that as the steam condensed the pressure of the external air would cause the tin container to collapse. In each case the experiment failed. Firstly, because the tin was too small and of too sturdy a construction; secondly, because the cork leaked and the cooling was not rapid enough; and thirdly, an admirable two-gallon paint tin with tight rubber stopper had been obtained, but on subsequent investigation it was found to be lined with congealed dry paint to a thickness of at least an eighth of an inch, and would probably have resisted all attempts to crush it, had the atmospheric pressure been as much as 100 lb. to the square inch!

In spite of all forethought and care things sometimes go wrong. The science teacher should have enough in reserve to keep the lesson going and should cultivate a calmness of attitude which will not be perturbed. Reserve apparatus is always useful. The practical books cannot give account of all the possible unwanted phenomena which may occur; for instance, our damp climate and continuous chemical fumes may make apparatus for frictional electricity unusable without special treatment; slight impurities will work havoc with certain experiments in chemistry, etc.

4. Lessons often suffer from bad arrangement of the experiments. Instead of spacing the demonstrations throughout the lesson period, the experiments are finished at an early part of the lesson, or are rushed in at the end. Sometimes there are dead periods of waiting for water to boil or other things to happen; a student once confessed to me that he never realized how true was the old adage, 'A watched pot never boils', until he tried to give a demonstration lesson. Although a demonstration lesson has little in common with a conjuring entertainment of the Maskelyne type or an operation in surgery, there is the same necessity for a careful anticipation of the order of the difficulties as they are likely to appear, and a thorough preparation of all apparatus and equipment which is necessary both for normal work and in cases of emergency. Nothing in all teaching gives the pupil the same feeling of 'flatness' as a badly prepared science lesson, where nothing 'works'.

5. The value of a lesson will be enhanced if the teacher makes it his business to be sure that every child can see. The assistance of children should be sought for some experiments but they should stand where they do not obscure the view. Specimens should be handed round and children should have a chance of handling them. A home-made episcopes will often render easily visible certain phenomena which can only be seen under normal conditions at close proximity. Experiments which are performed in glass flasks, beakers or test-tubes benefit by being backed with white tiles, or sheets of white or black paper. The writer once visited a lesson, on the burning of magnesium to form an oxide, which in some respects might have been quite effective. The class was a large one and the children at the back had no idea of the metallic nature of magnesium, but thought it was a very special substance which looked like thin white ribbon and burned with a very bright light! When given a small piece to handle a child realizes that it is a white metal of very light weight, which soon loses its brightness when exposed to the air.

In the time-honoured scheme for the preparation of lessons in training college courses the five 'Herbartian' steps do not figure as prominently as of yore. Nevertheless, some form of prepared notes of lessons is useful as a guide for the beginner. It has been objected that formal notes prevent young teachers from giving a broad treatment, or in the event of a departure from the preconceived arrangement, are the cause of the lesson 'going to pieces'; but without the notes, particularly of the *procedure* of the lesson, one imagines that things would have been much worse.

The teacher should have a clear idea of the *Aim* of his lessons and realize that the use of the same material does not necessarily imply that the aim must be the same. Then follows the *Preparation*, that is, the background in the minds of the pupils which provides the basis of the lesson about to be given. After this comes a very short statement of the *Matter* of the lesson, that is to say, its scope and the topics to be considered. The real lesson is considered under the heading *Method* or *Procedure*, wherein should be some indication of the development of the lesson as it is to be given, some idea of the questions to be asked, the actual framing of them and to what they are intended to lead. The art of questioning is of paramount im-

portance in any successful lesson, but the questions will fail if they are ambiguous or lead nowhere in particular. A good deal of the matter of the lesson can be obtained from the children, but the teacher will have to act as a selector and a leader. A statement of pictorial illustrations to be shown or experiments to be performed should be given. The power of verbal illustration is a useful gift but nevertheless some of the best teachers have little power of exposition. Teaching methods are very personal things and no general rule can be laid down, but it is safe to say that any method which does not keep the children employed in a variety of ways is not going to be very successful. Talking or 'lecturing' too much on the part of the teacher, however eloquent he or she may be, is soon fatal to interest; but, on the other hand, pictorial illustrations, stimulating questions, experiments with the assistance of the children, and the reading of easy passages in general scientific literature will go far to sustain attention.

A good blackboard summary will serve to prevent the teacher from wandering too far from his scheme, and it also acts as a means of recapitulating or revising quickly the salient points at the end of the lesson.

We add examples of 'prepared lessons', but they are only suggestive and need not be taken as models — and it would be trite to say that the very best Lesson Note-book is no guarantee of vital and interesting class work.

I

The following lesson is one of a series of lessons on bacteria and other disease-causing organisms.

Aim of lesson: to illustrate the way in which insects can serve to transmit micro-organic disease, and to show how a knowledge of the habits of the insects has led to a control of the disease.

Malaria is chosen as an example of disease.

Previous Knowledge we can assume,

- (a) a knowledge of the structure of insects, with the life history of the butterfly (egg — larva — pupa — imago);
- (b) the general structure and mode of life of bacteria;
- (c) a knowledge of the phenomena of surface-tension is *not* to be expected.

Material

(1) Malaria has occurred in many regions: it is more prevalent in the tropics than elsewhere. The Panama Canal construction was delayed by mortality due to malaria, together with yellow fever.

(2) Originally it was thought that the disease was caused by 'miasms' arising from marshy land and decaying vegetation. Ross, together with Manson, showed that the disease was actually due to the carriage of a protozoal infection from one person to another by a mosquito (anopheles).

(3) The mosquito (belonging to the Insecta, with mouth parts adapted for sucking and piercing, and passing through a characteristic life history of egg — larva — pupa — imago) breeds in the water. The larval and pupal stages are aquatic, breathing being accomplished by means of breathing tubes which float in the water surface — held up by surface tension.

(4) By knowing the life history of the mosquito and its connection with the disease, men have been able to control malaria. The number of mosquitoes has been reduced by:

- (a) the draining of useless stagnant water;
- (b) application of oil to surface of water (reducing surface tension and hence 'drowning' the larvae and pupae);
- (c) screening of required water from mosquitoes;
- (d) use of natural enemies — certain fish.

(5) Some people may be 'mosquito-carriers' — showing no symptoms of disease. The disease may be eliminated from them by quinine, atabrine or paludrine treatment.

(6) The use of D.D.T. and similar chemicals.

Method

Link up to lesson with previous work on bacterial diseases, and modes of transmission. Malaria is due to protozoon and is transmitted by means of a mosquito.

Give very brief account of older 'miasm' theory: mention Ross and Manson as showing the actual nature of malaria and the mode of its transmission — what does the word 'mal-aria' mean? To what class of the animal kingdom does the mosquito belong? What other example of Insecta do you know? What is characteristic of its life history? In the same way, the mosquito carrying malaria

has egg, larval, pupal, and imaginal stages. How does the mosquito differ from a butterfly?

(1) Its mouth parts are adapted for piercing. Show with the micro-projector and a large diagram the mouth parts of a mosquito.

(2) It is aquatic. How does it obtain an oxygen supply? Demonstrate the 'apparent skin' on water by floating a needle.

Can you suggest a connection between 'mal-aria' and the mosquitoes? — the latter breed in marshy areas producing bad air.

Can you suggest how to control the disease? — elimination of the mosquitoes. How can this be done?

Show the action of oil on water surface by adding paraffin to surface of water with floating needle; mention finally the use of quinine.

Summarize and close the lesson by reading two short passages.

(1) The anti-malarial campaign in the Panama Canal zone—quoted from Boyes' *Mosquito or Man?*, 1910, pages 81 and 82.

(2) Ross's mission to Ismailia and its results quoted from Dobson's *Ronald Ross — Dragon Slayer*, 1934, page 79.

Illustrative Material

(1) Large chart (to pin on blackboard) showing in indian ink outline drawings of egg, larva, pupa, and adult mosquito (*Anopheles*).

(2) Blackboard reproduction of Ross's sketch of *Anopheline* mosquito in act of biting.

(3) Microscope slide of mouth parts of mosquito—shown with micro-projector if convenient.

(4) Experiments showing surface tension of water, and decrease of this on addition of paraffin oil.

(5) Quotations illustrating activities of anti-malarial campaigners.

(6) Photographs from Boye's *Mosquito or Man?*—stagnant pools.

II

Notes on demonstration lessons on the generation and transmission of electricity.

Age of children, thirteen+

Aim: To show the practical application of previous work on

electro-magnetic induction. To introduce the idea of the convenience of alternating currents for generation and transmission.

Previous Knowledge

The simple experiments of Faraday on induced currents at the make and break of circuits, elementary work on electric circuits as in lighting and heating of houses, etc.

Matter

(1) When a wire is moved in a magnetic field an electric current is generated in it, depending on:

- (i) The length of wire.
- (ii) The strength of the field.
- (iii) The speed at which the wire cuts the magnetic field.
- (iv) The resistance of the wire.

(2) Demonstration of alternating current produced when a coil of wire is rotated in a magnetic field. Model dynamo with slip rings at one end of the axle and segmented commutator at the other. Various types of dynamos shown in models. The dynamo used as an electric motor (car dynamo).

(3) A simple static transformer consisting of two coils of wire wound on Stalloy laminations. How alternating current may be transformed, as it produces a magnetic field varying in a wave-like manner.

Changes of voltage and current by transformers. The convenience of high voltages in distributing electricity.

Method

Introduce the subject by mentioning the 'Grid', electric power and lighting. Recall the experiments of Faraday, by showing induction of current by thrusting a bar magnet into a coil of wire the ends of which are connected to a galvanometer. Notice what happens:

- (i) When the magnet is going in.
- (ii) When it is at rest.
- (iii) When it is coming out.

Repeat the experiments using a smaller coil of wire (through

which a current from a battery is flowing) wound on a piece of soft iron instead of the bar magnet.

Leave the small coil inside the larger one and interrupt the current flowing in the small coil by a small cog wheel and spring 'brush' fixed in the circuit. Observe what happens in the large coil connected with the galvanometer.

By using a model dynamo with permanent magnet and a single armature winding brought out to slip rings and spring brushes at one end of the shaft for alternating current, and to a commutator (a ring cut into halves) and brushes at the other for direct current, demonstrate the action of dynamos.

Other model dynamos should be shown and old car dynamos (also sometimes functioning as motors) can be used for demonstration. (Children should be encouraged to make models from simple materials, which will light flash lamp bulbs or alternatively may be used as small motors.)

Make a simple transformer by fitting two coils to Stalloy laminations. Recalling Faraday's work, why is it that A.C. may be transformed by such a 'static' device whereas D.C. cannot be used? From our knowledge of dynamos and motors suggest a way of transforming D.C. from one voltage to another.

In transforming currents the advantage usually lies with A.C. Further demonstrations may be given with a 'mains' transformer as used in A.C. wireless sets, and pictures of the oil-filled commercial transformers should be shown.

Why are high voltages used in transmitting electricity over long distances? A high voltage means fewer losses from heat owing to the resistance of the cable, and a thinner cable may be used. Cables and other apparatus necessary for distributing electricity are more expensive than generating stations.

Demonstrate the use of transformers and high voltages by means of a model. The overhead wires may be represented by two lengths of Eureka or other resistance wire (a yard or two of this may be regarded, as far as resistance is concerned, as the equivalent of a considerable length of copper or aluminium conductor). Show that a small home-made A.C. dynamo which is just sufficient to light a flash lamp bulb will only do so dimly when the 'transmission lines' of resistance wire are placed in the circuit. If the

current is first transformed up in voltage (say twenty times) by a home-made static transformer, then applied to the transmission circuit and finally transformed down in an inverse ratio by another transformer, the flash lamp bulb glows almost as brightly as if there were no resistance in the circuit.

(Children will probably inquire why there are three carefully insulated wires on each Grid pylon. Three-phase alternating current raises a few further difficulties but simple wave diagrams and graphs, and a three-phase model generator turned slowly will serve to explain its action and will lead to the understanding of the reason why it is used so often.)¹

Apparatus

Bar magnet, piece of iron, cotton-covered copper wire, dynamo made from old magneto, galvanometer constructed from magneto magnets, transformers (made by winding bobbins with different numbers of turns on formers and fitting to Stalloy laminations), flash-light bulbs and holders.

Illustrative Material

(1) Pictures of Faraday discovering electromagnetic induction, large generating stations, distribution of electricity, various pictures of the Grid and its equipment are obtainable from the Electricity Development Association (consult the manager of the local electricity offices and showrooms).

(2) Projection of parts of 'Electromagnetic Induction' films loaned free from 'Central Film Library', Imperial Institute, South Kensington, S.W.7.

(3) Visit a generating station.

Summary

The advice given by Fowles in his Lecture 'Experiments in Chemistry' is still worth recalling:

- (a) The apparatus should be ready before the class assembles.
- (b) New experiments should be tried over beforehand.

¹ It should be pointed out that with modern valve technique the problems of high-voltage transmission and transformation of direct current are now largely solved.

(c) A reserve of spare parts for the apparatus should be on the bench.

(d) If an experiment fails it is inadvisable to seek the cause unless the class is well in hand, when the search is profitable.

(e) If a sequence of experiments is intended, it is advisable to follow the advice of Faraday and arrange them on the lecture bench in the order in which they will be performed.

(f) Get promising members of the class to help with the experiments.

In an American Survey¹ of the most common faults in the technique of giving science demonstration lessons, made some years ago, the following points were noted:

1. The apparatus was not ready or was insufficiently prepared.
2. There was a failure to show how the demonstration fits into the teaching unit.

3. Some important facts of the experiment were overlooked.

4. No time was left for the recording of the data.

5. The blackboard was not used to simplify the issue where necessary.

6. No reason for the particular technique employed was given and the experimental controls were overlooked or not given sufficient consideration.

7. When the class was questioned the 'recall' type of question was used instead of the 'reflective' type.

8. Teachers used words which were unknown to their pupils and took no trouble to explain new terms.

9. Persistent and continuous talking on the part of the teacher did not challenge or stimulate the pupils.

10. Minor facts were given as much consideration as the major ones.

11. The teacher formulated the results and generalizations rather than requiring the pupils to do so.

12. The teacher failed to emphasize the generalizations and to show their implications.

¹ Edith M. Selberg, in *Science Education* October 1932, Vol. 16. 'A plan for developing a better technique for giving science demonstrations'.

13. The students' interest for further study was overlooked or not stimulated.

14. The teacher failed to show how the inductive methods of science should lead towards a generalization.

15. The teacher failed to encourage the pupil to suspend his judgment until adequate data upon the problem were obtained.

16. Insufficient drill was given in the formulation of the generalization or its application.

THE SCIENCE LESSON—II

Practical Work in Science

THE achievements of modern science are due to the application of the experimental or inductive method. Centuries of purely deductive reasoning, from the days of the Greeks, had not produced the same utilitarian results as a few decades of the experimental method. The face of the earth has changed, scientifically speaking, more in the last hundred years than in any previous century! Apart from the necessity of practical methods for the development of scientific knowledge, the truth of the maxim, 'Learn by doing', is undeniable from the teaching point of view. Enlightened practical work will naturally take a prominent place in any science course, even where there is no laboratory as such. Fortunately, in the new reorganized schools which are growing up, suitable science rooms are built giving plenty of floor space, but even where there is no proper accommodation much can be done in the school garden, the handicrafts room, or even in a classroom with some rearrangement of desks and benches.

Some of the troubles often connected with elementary practical work in schools may be summarized as follows.

The work has had no real connection with the common 'scientific' operations of everyday life; it has been old-fashioned and formal, and hence has unduly limited the scope of 'theory' lessons designed to back it up. Indeed, school practical work has not even had much relation to work in factories and commercial laboratories in later life, as a visit to any of these clearly reveals. The child learns highly specialized operations which he will probably never have to do again when he leaves school, but things which have a practical value in after school years are frequently omitted. Such a course may be justified in the later years of grammar school and university courses but it is indefensible in other post-primary schools. The pipette, the burette, the carefully weighed crucible

have little connection with real life, but we must admit that manual dexterity acquired by the handling of apparatus and facility in the use of accurate measuring instruments are not only the basis of scientific observation but are a very useful form of training which may be of assistance in many walks of life in subsequent years. There is a 'ritual' of the laboratory which can prove very irritating, for after all there is no virtue in the apparatus itself, it is merely a convenient tool; a hammer does not make a box, a piano a sonata, or a 'calorimeter' (even of seamless spun copper) a specific heat determination. Very often, indeed, the common domestic gas ring is far more useful than the Bunsen burner, the small glass jug than the beaker, the sliver of wood than the spatula. There is bound up with this worship of apparatus the 'false' accuracy which shows an entire lack of intelligence in the matter of errors and scales of magnitudes. To take an example, in a simple heat determination a 'calorimeter' is accurately weighed to the nearest centigram, water is added and another careful weighing takes place, and so the experiment proceeds; but owing to considerable errors which can hardly be avoided in the 'method of mixtures', as usually done in schools, the results are not accurate to within five or even ten per cent. The point is not that the first accuracy is to be deprecated, indeed scientific measurements should always aim at refinement, but the time and trouble expended in the early part of the operation is not justified by the results; and a large tin can into which 250 cc. of water is measured would yield results which are at least as accurate, and a saving of time would result.

In introducing the child to practical work it is well to bear in mind that he will have anticipated his first lesson in the laboratory with some enthusiasm, and teachers must be careful to see that the spirit of curiosity and delight are preserved. The child's joy is soon damped when, perhaps at the age of eleven or twelve, he enters a quite attractive laboratory full of interesting apparatus, only to find that the first work is the accurate use of the metre scale, to be followed by various other elementary physical measurements, culminating at the end of the year in the use of Nicholson's Hydrometer and Specific Gravity bottles; for work with Nicholson's Hydrometer is quite artificial and it would have been much more

valuable to have used a weighted test-tube instead of the hydrometer, and a medicine bottle in place of the expensive S.G. bottle. Practical work has not torn itself free from the stranglehold of the old physics books, which were excellent sixty years ago. Much of this traditional apparatus still persists in the catalogues of the scientific instrument makers, and it is at once expensive and of little use. The money expended on it might with advantage be saved towards such really useful things as a good micro-projector or projection lantern. Quite apart from work in elementary physical measurements time is still wasted during lessons in such operations as drying mercury, filling barometer tubes, etc., and one frequently finds that the essential observations are thrust to the end of the lesson where there is inadequate time to deal with them.

In many physics and chemistry laboratories a 'card system' exists, for giving the child a certain amount of guidance in his work. The use of cards has certain obvious advantages, it saves time and worry for the science master, but the system is too stereotyped and makes no allowances for individuals. Unless there are several cards and sets of apparatus for each experiment there is an unfortunate tendency for each pair of children to be doing different work. The practical work then bears no relationship to the other lessons in science and, moreover, merely becomes a series of topics, in no particular order and susceptible to no logical development. The cards should be a 'home-made' product and the teacher should never use cards which are not framed with a view to the use of the available apparatus and the peculiar conditions of his own laboratory work. Usually cards are satisfactory in that they give short instructions which enable the pupil to set up his apparatus, but they fail because they do not sufficiently encourage careful observations and they reduce what must always be a matter of intelligence and judgment to the level of a 'rule of thumb'. In the future we ought to expect a more enlightened laboratory method than this which at best is a *pis aller*. Good team work with an idealized 'heurism' should be applied whenever it is possible.

The card system could be extended, or sheets of instructions supplied so that the directions, without being obtrusive or supplying information which can be obtained by intelligent observation, direct the attention by simple hints, to the many phenomena, per-

haps small in themselves, which may be seen even in a simple combustion experiment. Unfortunately, many results appear to be anticipated and the phenomena which with the experience of many years seem to have no bearing on the particular result we desire, are purposely overlooked. This is the very antithesis of real scientific investigation which consists in observing the phenomena under as many conditions as possible, without bias, and often by a very lengthy process abstracting something which seems to be common to each experiment. If the apparatus collapses during an experiment or if results are obtained which do not conform to expectations we explain this as being due to impure chemicals or inaccurate thermometers and the probability is that we are right, but nevertheless we should bear in mind that it was in cases which did not conform to preconceived ideas that new scientific discoveries were made. Dr. J. A. Paris going one day into Faraday's laboratory, remarked to the latter, rather sarcastically, that he was using a dirty tube containing drops of oil for his scientific investigations. The following day came the terse reply, 'The dirty oil was liquid chlorine!' The very phenomena which have refused to fit former notions and traditional laws have been the starting points of vast new progress. Many such cases flash through the mind — the anomalous positions of certain chemical elements in the Periodic System, the radiations of a black body and the Quantum theory, Einstein's theory and the hitherto inexplicable behaviour of the planet Mercury in its orbit, which refused to be explained satisfactorily by the Newtonian mechanics.

In school laboratory work the tendency is to draw conclusions from insufficient evidence. An experiment performed once or twice proves very little when we come to examine impartially what we are justified in stating as a result. The writer remembers a lesson during which a teacher poured solutions of sulphuric, nitric, hydrochloric, and acetic acids into four test-tubes containing blue litmus, and the class duly noted down the 'law', 'All acids turn blue litmus red' — which to start with is not true, and even if it were, no 'law' can be established on such slender evidence. One may with equal justification take from the pocket a sixpence, shilling, florin, and a half-crown and say, 'All English coinage is silver'. The demonstration of an established 'fact' should not be

confused with a 'proof', at which it is exceedingly difficult to arrive.

Note-books should be kept as a record of actual work done and observations which have been made. If the experiment fails this should be mentioned and the reasons sought. Reticence should be observed in drawing conclusions and sweeping statements should be avoided especially when only a few observations are possible. No better exercise in the writing of clear simple English could be found than the description of scientific experiments and observations. Children will find great inspiration in examining the actual record books of the great scientific workers now preserved in the museums, or failing this reprints and facsimiles of their work can often be obtained. They will at once grasp that in most cases the apparatus was simple, perhaps made locally, or adapted from easily obtained articles, that the experiments were conducted in homely surroundings, and that resource, patience, and years of careful thought were necessary. It will be seen how one experiment suggested and led to another and how the character and personality of the man shone through all his work. The nocturnal researches of Darwin in his own garden on the earth worm are an example of the simplicity and variety of the experiments, and the immense amount of reasoning and patience necessary both to devise the experiment and to interpret its results.

Several times each term pauses may be made in the practical course so that the teacher can discuss results, give demonstrations, and show the application of the laboratory work.

It is useless to expect classes of C and D children to make intelligent observations and to draw satisfactory conclusions from the ordinary experiments. Their salvation will often be found in a practical study which many would hesitate to call science at all. In the winter they can investigate the working of simple pieces of machinery by actually taking them to pieces, and in summer they will find gardening on a simple scientific basis will not tax them unduly. Simple experiments to illustrate the work on hygiene should form a part of the studies of every child, even of those of poorer intelligence, indeed the inculcation of sound principles in health matters is probably more important in this type of child.

In the past, experiments of a physical and chemical nature have

been quantitative, but in secondary schools more general and qualitative experiments should be introduced, care being taken to avoid the impression that accuracy does not matter, but rather to show the difference between a demonstration and a careful determination which can often only be done with the expenditure of much time and the use of special apparatus. Here science reading books and accounts of original researches are useful, for the story of the search to reduce errors and to overcome difficulties is just as fascinating as an adventure story; and it is a quest which never ceases, for every year brings the tale of man's further penetration into the Cosmos with larger and better telescopes, and his greater control of the very small by improvements in precision instruments. In school laboratory work the rough estimate is as important as an accurate determination, particularly if it is accompanied by an endeavour to foresee and to investigate where errors are likely to creep in. Indeed, sometimes the avowedly rough estimate, accepted as such, is more satisfactory than a result which is accepted as being accurate but in reality is subject to grave errors owing to the manner of its performance. Few children realize how errors are magnified during the various operations of the experiment. Intelligent approximation, a realization of the idea of *comparative* magnitudes and errors, a consideration of quantities which can be neglected and the reason why, are a vital part of all quantitative investigation. Usually such topics are only for the better and older children and without an intellectual grasp of the problem of error most quantitative experiments lose a great deal of their significance and are better omitted at a stage where the mathematical counterpart is not clear.

In later school years some idea of the way in which observations are made in practice so that the mean result is found, together with an estimate of possible errors, may be arrived at by taking the results of each pair or group of pupils working with similar apparatus (or if there is only one piece of apparatus, by taking the results of observations made with it by a number of pupils one after another). There is a great deal of scope here for the introduction of elementary statistical methods and at once the subject is related to actual practice in real quantitative investigations. The matter is one for the grammar school rather than for

the modern school, but it is surprising how such an important topic, at the very heart of all inductive science, is overlooked even in formal science teaching in the universities.¹

All teachers should be teachers of English and pupils should learn to make written records of their own composition which will be of value to them, a useful record of their work and good enough for revision purposes. If training is commenced early in the secondary school course then the amount of time spent is by no means excessive. The dictation or copying of notes must be regarded as an expedient which cannot usually be justified on sound educational grounds. The essence of the method at the start is to make sure that the material is understood by and expressed by the class as a whole and to be content with very brief accounts so long as they are original.

For example, if a record is required of some experimental work, a member of the class should be asked to give an account (with help from the teacher when it is really necessary). The combined efforts of the class should suffice to produce a sentence which may be written on the blackboard. At first two or three sentences will suffice, for care must be taken to prevent the science lesson from becoming tedious.

Before proceeding to the direct writing of observations and experiments in note-books it is better to call on a brighter member of the class to give a verbal account or read aloud what he is composing. This has the double advantage of making sure that the correct facts are being recorded and also of giving assistance to the slower members since the purpose of this activity is not merely to give training in self-expression but to get methods and facts recorded correctly in individual note-books. All essential facts should be checked in the right order at the end.

The method may be varied by asking the class to make notes of the sequence of events during a demonstration, or again the notes may be made immediately after the demonstration. If apparatus is described it should be done by relating it, part by part, to the function which it has to perform as a whole. All generalizations, definitions and 'laws' should be worked out by class discussion before they are written. The ideas should be

¹ See *Statistics in School* (Blackwell), by the author.

matched to the age and intelligence of the children and all technical terms should be fully explained. Successful and easy writing is only possible if there is full understanding, and where this is not the case no memorizing of dictated accounts can be of any value to the individual. In fact, this is an example of 'verbalism' in its most vicious form.

When the third form is reached some reasonable facility to write a short paragraph may be expected. The fourth and fifth forms should be able to write extensively if need be. It is essential that, at all stages, the teacher must make certain that the class as a whole has the outline in mind and that the slower members are helped along tactfully. Methods should be varied and it should be obvious to the class that the lesson has a clear purpose, and is interesting. Material which is already adequately treated in a text book should not be written out, but a note should be made of the appropriate reference so that the studying unit becomes not merely the note-book or text-book, but these are supplementary to one another. Occasionally, cyclo-styled material may be distributed where time is not available for all the written work necessary. There is no merit in mechanical copying.

CHAPTER VI

BUILDING UP THE SCIENCE SCHEME

THE outline of a scheme for a science course in senior classes given on page 20 and quoted from the Hadow Report is not intended to do more than offer suggestions. Very often successful work is done in science where astronomy and meteorology only get passing mention, but it is safe to say that no scheme can be called satisfactory if it fails to give an important place to biology, and its applications to hygiene, domestic science (in girls' schools), and gardening. In framing a scheme the former neglect of biology, apart from descriptive Nature study, should be borne in mind. Teachers and students in training, whose main qualifications are in the physical sciences, are becoming aware of the necessity of broadening their outlook to include the study of living things, and they find that the knowledge gained gives a wider meaning to their original subjects, and they see that physics and chemistry are excellent foundations for biological studies.

A school in a rural district will naturally tend to stress topics concerned with agriculture and animal life, whilst children in towns might benefit from additional work in physics, mechanics, and engineering; girls will require domestic science including chemistry in the home, hygiene, and the applications of heat and electricity; and the less intelligent C or D children need a practical treatment of everyday topics with simple science reading. In many districts, the local industries may serve as a basis for a part of the course, and will provide a number of topics of immediate interest without being vocational. It is a mistake to be limited unduly by local considerations, for the town boy will need to know something of gardening and life in the country, and the dweller in the village, even if he works on a farm later, must have some knowledge of machinery, chemical substances, electricity, and its applications. Indeed, the broad treatment of science may inspire the child with ideas for a possible future career. A mere absorption into local industries is perhaps inevitable in a number of cases, but it can hardly be considered ideal.

Eleven, the age at which primary school life gives way to work in secondary schools, is too early to begin courses in science which give a systematic treatment, and clearly, it would be folly to deal with physical topics only in the first year, chemistry in the second, and biology in the third, for this would not only result in a failure to preserve the unity of science but it would limit the treatment of the particular topics which were to be first considered; and each year's work, being devoted to the same type of study, would prove tedious. Probably the best way in the secondary modern school is to adopt a concentric method, either throughout the course or until the later stages are reached. At first a number of simple related topics, not strictly assignable to any particular branch of science, are dealt with from the point of view of the pupil's life and experience, and as the child develops, the field is gradually enlarged and the treatment is made more comprehensive. Each subject suggests and leads naturally to another one. Many teachers feel that a concentric method which deals with the chief branches of science is difficult to work out. They argue that a real concentric method leaves many important avenues obscured and becomes too general. A scheme which is favoured by some science teachers is to take the term as a unit. The four-year course for boys then works out as follows —

	<i>Year I</i>	<i>Year II</i>	<i>Year III</i>
Term I.	Properties of Matter.	Chemistry.	Mechanics.
Term II.	Heat.	Light and Sound.	Electricity.
Term III.	Biology.	Biology.	Biology.

Years IV (and V)

Term I.	Power and Raw Materials.
Term II.	How Scientists work. Science and other subjects. History of Science in relation to social needs.
Term III.	Evolution. Thinking and Doing. The Elements of Social Biology.

Biology is taken in the summer term as material from woods, ponds, and gardens is more readily obtainable. Some astronomy is introduced in this course in the work in 'properties of matter' and light, meteorology in heat and biology, hygiene is introduced

wherever possible in biology, heat and chemistry; and when desirable, the various branches are correlated. The weaknesses of the scheme are that electricity is not mentioned until late in the course and that it is false to think that biology is essentially a third-term subject. The autonomy which is preserved in the various branches of science for academic purposes can yield unfortunate results in secondary schools. Nevertheless, there are many science teachers who combine a scheme such as the one given above with a concentric course, for in the work of each term they stress a few topics related to a particular branch of science or a few 'projects' in addition to the normal development of the concentric method. When a fourth year becomes available there will be a welcome opportunity to extend the above topics and apply them to human affairs. Time will also be found to deal with scientific methods and their applications to specific problems.

Naturally, the amount of time which can be given to science each week will influence the scope and methods of the course. Three periods should be considered the minimum, and in relation to the time given to other subjects this cannot be considered exorbitant. Indeed, if no hygiene teaching is undertaken outside the science course, a larger amount of time cannot be considered excessive. Many schools find that a quarter of the whole time devoted to science spent in practical work, apart from gardening, is satisfactory. Many teachers have devised means of saving time in practical classes in order to get the maximum number of experiments done in the time available. Although little official laboratory assistance can be expected, children will often undertake the preparation of simple apparatus. For instance, at several schools weighing is done on simple steelyard balances, accurate to within a gram, which the children have made for themselves.

In some schools the greater part of the science work is conducted in the laboratory and practical work is done where the need for it arises, and this absorbs from a third to a half of the time devoted to science. Above all it must be stressed that each teacher must make his own course, bearing in mind the minimum desiderata which have been outlined in the Hadow Report, for he alone knows his pupils and the district in which they live. His treatment will depend on these factors and on his own natural abilities.

The special problems of Science Teaching in girls' schools

In the past science in girls' schools has suffered because:

1. Science was not regarded as a very important subject for girls and consequently less time was devoted to it.
2. It was often confined to descriptive botany.
3. The physical and chemical foundations of science were entirely overlooked and not only was the scope of the subject consequently narrowed but the essential basis of the biology was neglected.
4. The teaching of hygiene and domestic science were separated from their foundations in elementary general science and thus their treatment was bound to suffer.
5. Little attempt was made to apply such science as was done to an understanding of its applications in our homes, our daily lives, and to the larger problems of the world and human health and happiness.

Science is just as important in the life of the girl as in that of the boy. Indeed, in her later domestic work the girl often needs the broader knowledge of its applications. It is, of course, unwise to present science as the only thing which is of importance in the home. An appreciation of the chemistry and physics of the kitchen does not necessarily imply a good cook for there are always artistic sides to the various tasks of the home. However, the application of scientific methods to the running of the modern home cannot fail to have a useful effect, and this will naturally include an arithmetical treatment of the weekly budget, bearing in mind Mr. Micawber's excellent financial advice.

From the utilitarian point of view science work in girls' schools, principally through biology, should form the basis of hygiene, including infant care and management, and domestic science which is related to this. The work, however, should not be confined to this, and apart from the more mechanical applications the girls' science scheme should have a great deal in common with that of boys.

It is necessary that every science teacher should devise her own course, having regard to local requirements, but the following

points which are sometimes forgotten should receive consideration in addition to the generally accepted work on hygiene and domestic science.

Mechanics, etc.

Levers. Muscles and Bones.

Simple mechanical devices used in the kitchen. Machines, sewing machines, pumps, flushing systems, water supply. Mechanics of buildings, clocks.

Heat

Heat and temperature, thermometers domestic and clinical. Temperature and cooking. Heat regulators, incubators, refrigerators.

Heat from fires, gas, electricity.

Heat insulation — hay-box cookers, clothing.

Ventilation, convection currents, domestic hot-water systems, radiation, bright and dark surfaces — thermos flasks.

Evaporation and keeping things cool. Heat and life. Development of bacteria. Heat and its effect on various constituents of food. Heat and chemical action.

Light

Simple experiments with mirrors and lenses. Light and heat related.

'Ultra-violet light' and its chemical action. Electric and gas lighting. Colour and colour schemes. Light and health. The eye, its defects, lenses and spectacles. The camera, how made and used. The cinematograph. The optical lantern.

Sound

Sound and noise. The transmission of sound. Musical instruments. The ear. Insulation for sound.

Electricity

How electricity is generated and transmitted (general treatment).

Electricity in the home (see p. 107).

It is essential that work on electricity in the home is not neglected.

Chemistry

Chemistry in the home (see p. 114).

Biology

Including physiology, bacteriology, gardening, etc. (see p. 125).

It is important that the treatment of the subject is kept broad by linking it with other school subjects, and if time does not permit of further work in school there should be opportunity for the reading of simple books on general science, for which Andrade and Huxley's *Introduction to Science* will prove admirable.

The Andrade and Huxley Course in Elementary Science

The majority of teachers prefer not to be bound by the rigid lines laid down by textbooks, as every teacher has his own individual way of approaching the subject, so that local conditions, the types of children in the school, and other particular factors are considered. The four books in the series *An Introduction to Science* by Andrade and Huxley, without being strict textbooks, form an excellent secondary school course. In order to complete the outlined course, science reading, either during short periods in class time or as home-work, will prove admirable. In grammar schools too there is often a need for suitable reading books in science, apart from textbooks, to act as a relief from more formal work in science, to broaden the scientific outlook, to apply the work to everyday life, to lead to an appreciation of the modern world, to hygiene and the care of the human body. In secondary and grammar schools where the science courses are confined to one or two subjects this is particularly necessary, and as there is not time or opportunity for the formal treatment of a large number of subjects, the study of readable books with suitable illustrations on general science is called for even more strongly. For such purposes it would be difficult to improve upon the four books by Andrade and Huxley, and the reading of such works will result in the stimulation of interest and the appreciation of the relation of science to life in all its phases — which are points of paramount importance.

*The Andrade and Huxley 'Introduction to Science'**Book I— Things Around Us*

This book gives a senior school first year treatment of general science as a whole, the aim of the book being summed up in the last paragraph: 'We see that whether we look at great machines or mouldy bread, at the starry skies or the starfish, at magnets or steam or crystals of sugar there is order and regularity, the study of which is science. Nothing is too ordinary to be interesting, nothing is too small to matter, nothing too large for us to try and understand. In this book we have looked at some of the subjects which fall within the range of science and learnt the first beginnings of that knowledge of their working which has been found out by the patient study of great men in the past.'

i. What is Science?

Interesting things around us. The stars in their courses. The planets and their satellites. All things obey rules. Things are not always what they seem.

Some rules about heat.

Things always behave in the same way if everything is the same.

What science means.

The science of living things. All living things come from seeds or eggs. Many things in animals act like machines.

ii. The Nature of Things

The importance of observing carefully.

Smoke and steam. More about steam.

The airy stuffs called gases, the behaviour of gases.

Different kinds of liquids. The behaviour of solvents — solids, liquids, and gases. Melting and boiling. The same things can be solid, liquid, or gas.

iii. Movement and Forces

Engines and horse-power, magnetic force, electric forces. The force of gravity. Weighing things, the way things fall. The centre of gravity — the conditions for a body to stand up. Tricks depending on the centre of gravity.

iv. Energy

Heat, light, and sound. Transformations of energy. Heat and work. Kinetic and potential energies. Light as a form of energy. Sources of energy — the travels of energy.

v. Air

The ocean of the air. The weight of the air. The pressure of the air. Proving the pressure of the air. How the air pressure holds up liquids. The barometer. The aneroid barometer. Warm and cold air. The water in the atmosphere. Frost and fog.

vi. Water

Water everywhere. Different kinds of water. Salt water. The density of water and ice.

What is water made of?

Chemical compounds and mechanical mixtures.

vii. Life

Plants and animals — Growth — Food — Men and machines — Heredity. Plants which are not green — germs of diseases — sterilization.

*Book II — Science and Life**i. Breathing and Burning*

Oxygen — Breathing is a kind of burning — chemical change — Burning and energy — different ways of breathing — Our bodies are slow combustion engines.

ii. How we move our bodies

Movement and muscles — Sinews. Joints and bones, levers. How muscles work in the body. How different animals move.

iii. How the Body Machine is controlled

Muscles are controlled by nerves — The brain — How we see — The brain helps in seeing — Seeing colours — Hearing, smelling, and tasting. Touch, temperature, and pain. Inside information. The different worlds in which animals live.

iv. Heat and Temperature

Temperature and heat. Measuring temperature. How heat travels. Some results of the rules of heat. Heat is needed for melting and boiling. Melting points and boiling points.

v. *Human Temperature. Human Health*

Ventilation — Air and sun — different kinds of food — Health and food — Exercise and sleep — Cleanliness and health.

vi. *How plants live*

Plants are built differently from animals — How water travels through plants — the food of plants — Plants and oxygen. The difference between plants and animals. Flowers and seeds. Insects and flowers. Seeds and how they are distributed — the usefulness of plants.

vii. *Some different ways of living*

Water plants — Water animals — different kinds of surroundings in our own country.

Book III — Forces at Work

i. *The World of Electricity*

Electricity in the service of man. Electricity in nature — animal electricity — frictional electricity. Conductors and insulators — Electrical attractions — Electrical instruments.

ii. *Current Electricity*

Heat effect of current electricity — the galvanometer. Chemical effect of an electric current. Electric cells. Electrical resistance. Electrical potential. Electrical units — the supply of electrical power. Frictional electricity and current electricity are the same electricity.

iii. *Magnetism*

North Pole and South Pole. Magnetic attractions. The magnetism of the earth. Electromagnetic induction.

iv. *Light*

Light and Sight. Lenses, reflection, colour.

v. *Inorganic Chemistry*

Different branches of chemical science — the balance in chemistry — Elements and compounds. Acids, bases, and salts. The manufacture of acids. Pure metals and alloys.

vi and vii. *Organic Chemistry. Hydrocarbons and Carbohydrates*

The peculiarities of organic compounds. Carbon and its properties. Petroleum and the paraffins. Carbohydrates — sugar, starches, and cellulose. Alcohol and fermentation. Coal and its products.

Book IV — Earth and Man

i. *The Earth and its Climates*

Classification and adaptation.

The earth is round — How the earth spins.

Measuring angles — Latitude and longitude.

Seasons and climate — Why the year has different seasons.

The world's air circulation — The world's water circulation.

The earth's belts of climate — Life in the world's cold belts.

The temperate lands and the desert belt — Life near the equator.

ii. *The Make-up and History of the Earth*

The make-up of the earth. The earth has a long history. Rock layers and how they are formed — fossils. How rock layers are folded and tilted — Troughs and domes in the earth's crust. Erosion and its effects. The history of life. Igneous rocks.

iii. *The Chemistry of Life*

The circulation of matter through life — the carbon cycle. Carbon and power. The nitrogen cycle. The phosphorus cycle. The wastefulness of man.

iv. *Soil*

How soil is formed. How soil holds water. The structure of soil. Harrowing and rolling. Early and late soils. The effects of lime. Ploughing. Plant remains.

v. *Agriculture*

Plant food — Manures and fertilizers. Nitrogen and agriculture. Soils, plant life, and scenery.

vi. *Development and the Stream of Life.*

The life story of an Animal. How a chicken develops. How developing animals are looked after. Plants develop as well as

animals. Other ways of development. The stream of life. The life of germs.

vii. *The Improvement of Living Things*

Animals and plants can change. Heredity and environment. Fertilization and genes. Heredity and the recombination of characters. Heredity and evolution. The deliberate improvement of living creatures.

viii. *The History of Science*

The beginnings of science, science in classical Greece and Rome. The beginnings of modern science, eighteenth-century science. Nineteenth-century science. Scientific methods and principles. Changes due to scientific progress—Science and the world today.

The following is a four-year course in 'senior' school science, which is actually in use in some Midland schools in industrial and city areas. The scheme is not given as a model but merely to show how an attempt has been made to cover a wide field which is at once useful and practical and permits further development. An endeavour has been made to utilize a discussion of common things around us as the starting point for each group of topics.

A Four-Year Science Scheme

Nature Study

1st Year

Seed structure.
Seed germination.
The earth-worm.
The house-fly.
Moths, etc.
Trees and Shrubs.

Breathing of living things

Air different after breathing.
What air is before being breathed.
What 'breath' is.
Air a real substance.
Air presses in all directions.
Great strength of air pressure.

How we breathe

How fish breathe.

Artificial respiration.

How we get a supply of fresh air into our homes.

Ventilation.

Heating our Homes

Laying a fire. Air necessary for burning. Gas burner; Bunsen burner.

Why a match 'lights'.

How we heat our homes. How we measure temperature.

Practice in use of a thermometer. Temperature and Health.

Why clothes keep us warm

Metal 'colder than wood'.

Air a bad conductor.

How our school is heated.

How water gets hot.

Our water supply

The 'tap'.

Water levels.

Where our water comes from.

How our water is purified. Filtration.

Salt from sea water. Evaporation.

Clean water from dirty salty water. Distillation.

Why washing 'cleans'.

Other solvents and their uses. Dry cleaning. 'Punctures'.

Why we oil machines

Parts of cycle. History of its development — Evolution of wheel.

Friction: causes; heat; elimination; uses; disadvantages.

Expansion of metals on heating.

Great force of expansion. Applications.

How we light our homes

The sun, candle, oil, gas, and electricity.

The camera and lenses.

The human eye.

Experiments with colour.

The telescope, microscope, and optical lantern.

Persistence of vision and the cinematograph.

How green plants feed

Mouths of a plant. Presence of starch.

Green leaves contain starch, water, minerals, carbon.

Starch composed of water and carbon. Starch and sugar.

How plants obtain their carbon.

How plants obtain water and food from soil.

What this 'food' is. Certain chemicals in solution.

How substances insoluble in water get into solution.

Acids and alkalies. Chemical action. Manures.

How plants get rid of excess water.

A typical flower and the work of its various parts.

Pumps

Drinking milk through a straw. Revision of air pressure.

Syringe; fountain-pen filler.

Bicycle pump. Valves; elasticity of air; compressed air.

Simple mercury barometer. Weather glass. Bicycle pump reversed for measuring air pressure.

Lift pump and air pump.

Force pumps. Limit of lift pump. Valve and centrifugal force pumps. Other applications of centrifugal force.

The heart as a force pump. William Harvey. The pulse.

The lavatory flush — siphon action. Control of water supply; ball valve; buoyancy.

Heating of homes and buildings

Revision of conduction of heat. Davy lamp. Convection currents. Winds.

How a fire warms us. Radiation of heat.

More about radiation. Application of principles. Thermos flask.

Rusting and Burning

A burning candle.

Preparation and properties of oxygen.

Rusting — oxidation. Prevention of rust. Revision of amounts of oxygen and nitrogen in air.

Burning of magnesium. Increase in weight.

How metals are obtained from ores

Heating of mercuric oxide; red lead.

Heating oxides on charcoal. The blast furnace.

How dampness is prevented in houses

New ways of building houses

Why a pen-nib has a slit in it

Other examples of capillarity.

Production of light by electricity

Circuit; conductors, etc.

More about conductors. Flash lamp and its circuit.

The battery of the flash lamp. Construction of the cell.

Making a simple cell. The Leclanché cell. Joining cells to make a battery.

Other applications of electro-magnets.

Thunder and lightning.

Why and how things fall

Gravitation. The Solar System.

Balancing objects. Centre of gravity.

Ice

Why it floats. Bursting pipes.

Rain, dew, frost, etc.

What food is; how food is changed in the mouth. The teeth and their care. *3rd-4th Years.*

How food is changed in the stomach.

How food is absorbed into the blood; main internal organs.

Weather and weather forecasting; barometers.

More about weather; depressions, etc.; charts.

Evaporation requires heat; maximum and minimum thermometers; wet and dry.

Rule of lever; principle of moments.

- Simple tools as levers; Mechanical Advantage; weighing by lever.
- The human skeleton; bodily movement; muscles and nerves.
- How a sash window works: (a) parallel forces; (b) single pulley.
- Other pulley systems and applications.
- Wheel and Axle; applications in the bicycle.
- Cogged wheels and gears.
- Telephone; cause of sound and how it travels.
- Telephone transmitter and receiver. The ear and how it works.
- Revision of electric bell, morse key and sounder.
- Electric resistance; different metals have different resistance.
- Resistance produces heat; lamp filaments; radiator elements.
- Electric pressure and current; volts; amperes; rheostat.
- How we measure resistance; Ohm's law.
- How we buy electricity; watts; power.
- Electricity and motion; electric motor.
- Generation of electricity; dynamo.
- Principles of steam engine. Expt. — Effect of pressure on Boiling Point. Capacity for heat of earth and water.
- Specific heat and climate.
- How we buy heat from the Gas Company; quantity of heat.
- The gas meter; how to read it.
- Latent heat and applications; melting of ice; steam; scalds.
- Why salt put on ice melts it.
- Principles of the petrol engine; explosion; to and fro motion converted to rotary; four strokes. Two-stroke engines.
- Revision of burning and its products; heating coal and making coal-gas.
- Hard and soft water.
- How to remove the hardness of water and why.
- Chalk; limestone; quicklime; use of lime.
- The manufacture of soap.
- Composition of water; hydrogen.
- Reproduction in plants and animals including man. The balance of Nature. Simple science methods of discovery.

In the case of C children the topic method is still used. Fewer topics are considered but these are taken as far as possible from the child's experience, and they are developed as far as the intelligence

Science Scheme for C Classes

Why we oil our Bicycles

What friction is and does — Heat caused.

Expansion caused by heat.

Friction a hindrance — or a help.

How a Bicycle Pump and Valve work

Air pressure. Compressed air exerts a force. Water syringe and pump.

How to Mend a Puncture

What 'solution' is.

How washing cleans us

Other solvents and solutions.

Grease insoluble in water — soluble in soapy water. Hard and soft water.

Removing Stains from Clothes

Candle grease. Heat melts, blotting paper absorbs. Use of solvents such as petrol, benzene, methylated spirit. Precautions in using such substances.

Why a Pen-nib has a slit in it

Water rises up narrow tubes. How a fountain pen writes. Other examples of capillarity. Damp clothes.

How Dampness is Prevented in Houses

Ventilation. Convection currents.

Why Water Pipes sometimes burst in winter

Expansion of water on turning to ice. Force of this expansion. Its use in hard soil. How life is preserved in ponds and streams.

How clothes keep us warm

Some things feel colder than others. Effect of cloth covering in keeping anything warm. Air enclosed in blankets.

Suitable clothing for various conditions.

How we breathe

Experiments to show air pressure and its strength. Muscular movement makes more room for air. Experiment to show action of diaphragm.

Magnets

Suspended magnets always point N.-S. Some substances are attracted. Iron filings, diagrams of lines of force.

Electromagnets worked from flash lamp batteries.

Thunder and Lightning

Sparks from Wimshurst machine. Rubbed substances giving sparks, lighting neon lamps and attracting light particles.

The House-fly

Its life history. How it can carry dirt and disease. Its life history compared with that of some other common insect. Caterpillars and butterflies.

Seeds and how they grow

The germination of seeds. Roots and root hairs. The cycle of plant life.

Trees and Shrubs

Trees and shrubs throughout the year.

With D children the scheme, while remaining practical and useful and depending on everyday happenings, is still further simplified. It is based on simple everyday practical activities of real value in life.

*Part of a Science Scheme for D Classes**How to lay and light a fire*

Necessity for air spaces. Things will not burn without air. Why a match 'lights', friction causes heat. Why a match-head flares into flame so vigorously — oxygen. Some substances burn more easily than others — petrol, wood, paper, coal. Some things have to be made hotter than others before they will burn. How cigarette-lighters work. Bunsen burner. A burning candle — why it gives 'light'. What air is composed of — rusting of iron, burning of other substances.

Why we oil our Cycles

Friction prevents free movement and causes heat. Heat causes expansion. Various examples to show expansion of metal and the force which results. How to prevent friction.

Friction as a help and as a hindrance.

Do not fill a kettle to the Brim

Expansions of liquids on heating. How we measure 'hotness' of temperature. Thermometers. Practice in taking various temperatures — air, water, ice, steam, breath.

Why a Fire Balloon Rises

Expansion of gases on heating.

Our Water Supply

Why it rushes out of the tap. How water is made clean and fit to drink. Various experiments on filtration. Germs and how they may be destroyed.

Why Washing Cleans

Various experiments on solution, including evaporation and condensation. Steam, clouds, fog, rain.

How water in a kettle gets Hot

Hot water is lighter than cold. It rises. Heated water expands.

Why smoke goes up the chimney

Hot air is lighter than cold. Air expands when heated.

Fresh Air and Impure Air

What fresh air is. Production of and experiments with oxygen. What impure air is. Experiments with carbon-dioxide. How fresh air gets into our lungs and foul air out. How we get fresh air into our houses and foul air out. Air is a real substance and has weight. How fish breathe — air dissolved in water.

Germinating seeds and growing plants breathe.

How Green Plants Feed

Germination.

How plants 'breathe'. The green colouring matter of plants. Experiments with growth of plants in water containing various substances.

A simple Concentric Scheme in use for B or C Children in a semi-rural area

In this school, which is in the centre of a large new estate forming a part of a city's housing scheme in close contact with the country, considerable stress is placed on work in the garden and develops itself in the order: *Body, Home, Garden.*

The necessity of keeping the body warm, nourished and clean:

(a) *Clothing* — the conduction of heat.

Experiments to show that the body generates heat but the clothes retain it. What are the most suitable materials for clothing purposes?

(b) *Combustion and Breathing*

Air for burning — the composition of the air — the need for ventilation — the methods of putting out fires. The idea of temperature and the methods of heating the home and school.

(c) *How does heat from different sources reach us?*

Conduction is one method but far more important are *Convection and Radiation*. Convection currents of air and application.

'Hot water pipes for heating'.

(i) Convection of water in pipe.

(ii) Conduction through the iron.

(iii) Radiation from pipes and radiators.

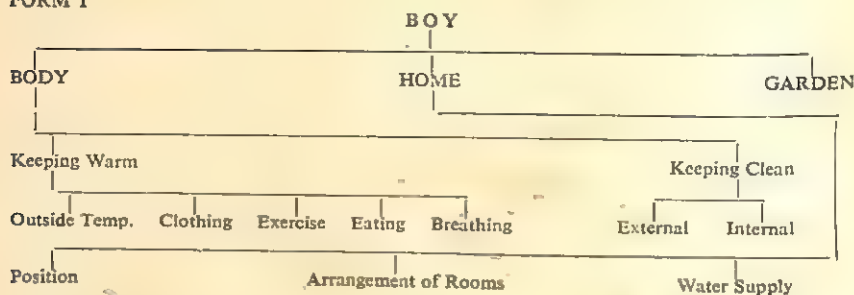
(What are the conditions of good radiation? Simple experiments will show.)

(d) *How is heat produced in our homes?*

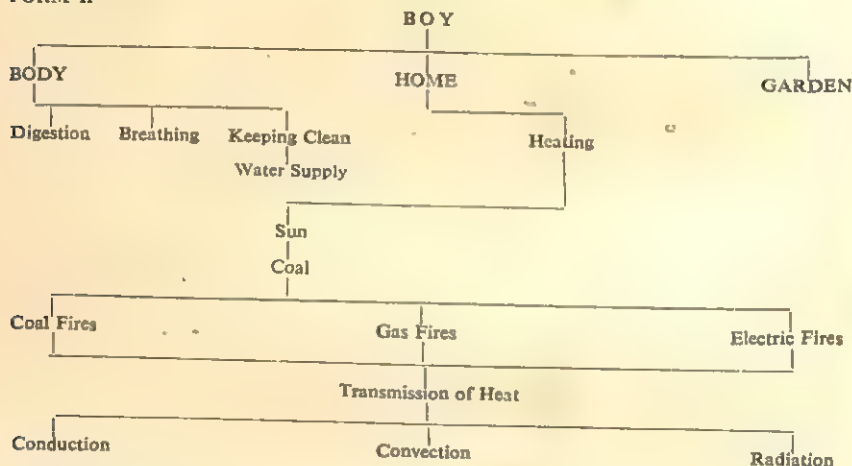
(i) Coal, coal-gas, by-products and their uses.

(ii) Electricity. The heating effect of an electric current passing through a resistance wire — using a thinner wire and obtaining a great temperature, we get electric light. Why fuses are necessary — how they work and how blown fuses are replaced. Switches and simple circuits. Electro-magnetism, electric bells, telephones, and motors. Electricity meters. How electricity is measured. Watts, amperes, volts. A very simple treatment of alternating and direct currents. Why the former type is becoming more general in Britain. 'The Grid'.

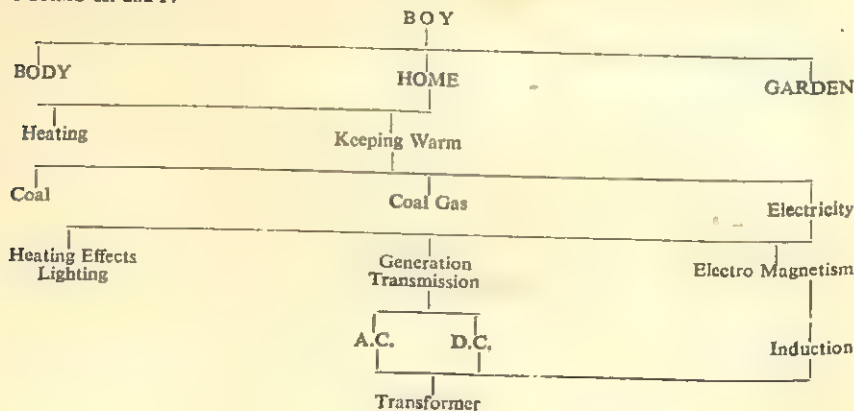
FORM I



FORM II



FORMS III and IV



Keeping Clean

Necessity of keeping the body clean without and within. Care of the teeth, skin, hair. Cleanliness in the school, home, and elsewhere. Dangers of dirt and microbes. Sanitation and disinfection. The water supply and the use of soaps. How a house is built to facilitate keeping warm, clean, dry, etc.

Keeping the body well nourished

Here the practical use of the kitchen garden is stressed. Plants are raised from seeds and cuttings, both out of doors and in the greenhouse. Scientific reasons are found for various operations, digging, hoeing, manuring, mulching, etc., and a number of experiments, for example on capillarity and transpiration, arise directly from this.

The action of frost in breaking up hard soil. The bursting of water pipes on freezing. Weeds and their eradication are linked up with the modes of seed dispersal examined during the junior school nature study course.

The study of pests leads to work on the life histories of insects, and this again gives suggestions for the control of the pests. The school apiary suggests many lines of study. The beehives and other apparatus are made in the workshop. The production of honey is undertaken practically. This leads to honey extractors and centrifugal force. The lives of the queen bee, the workers and the drones and the social life of the hive are dealt with. The fertilization of the queen bee by the drones is compared with the cross pollination of flowers.

At every stage the work is extended into various side-tracks and ramifications as far as is possible according to the intelligence and age of the children.

Apart from the work in the garden the Scheme may be represented as on page 70.

For details of a Four-Year Scheme in General Science see page 157.

Project Methods in Science Teaching

Modern teaching methods make provision for activity and co-operation between members of a class. The essence of modern

scientific research in all but fundamental principles is co-operation and good team work wherein each member contributes by using his peculiar knowledge and gifts. Projects as a part of routine school life are more prominent in the United States and in Scandinavia than in England. Projects absorb a considerable amount of time and the majority of teachers in Britain would use them as a part of their science work only. Care must be taken to avoid the possibility that projects give the children a superficial knowledge of a great many things but they leave an insufficient basis of sound fundamental principles.¹ Projects are best worked out with small classes or groups. A project may take the form of a constructional task by which a school farm or garden is run, an observatory or meteorological station made and used, or it may take the form of an investigation of the water supply, the electricity and gas supplies, the health services of the locality, the geology of the neighbourhood and so on. It is necessary that every member of the group should pool his or her knowledge and at the end of each project the work should be summed up in the form of an exhibition, a bound book, talks and demonstrations given by members of the team. The teacher can help as a leader and by careful questioning may be able to lead the team to probe for fundamental principles at the basis of their 'researches'.

Here is an example of a project on water undertaken by a junior form of a Girls' Grammar School.²

A Series of Lessons towards a Project on Water

This project is designed for children of 11-12 years, in their first year at a secondary school. It is planned to occupy ten double periods (each period of 40 minutes), i.e. a usual school term. Obviously many points can be amplified if desired or if time permits.

Useful Sources of Information

The Water We Use, Holmes. This is an extremely useful little

¹ Until 1931 the project method was the only one admitted for science teaching in the U.S.S.R., but for the reason we have mentioned it was then abandoned for 'polytechnization'.

² This project was devised and conducted by a science student, Miss Joan Champkins, at the Nottingham High School for Girls.

book, inexpensive, entertainingly written, and with clear, pin-men type diagrams.

A Little Book on Water Supply, Garnett.

The Thirst of Cities, Lauwerys and Glover.

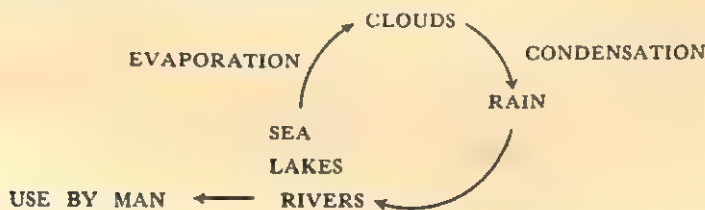
The Metropolitan Water Board is able to supply a historical magazine and pictures.

The local Water Board is probably also able to lend sets of pictures and information of local interest.

In a previous lesson the project was mentioned, and as part of their homework the pupils were asked to find as many pictures of water as possible, the idea of the project was explained, and in their art lesson a folder was made so that all written work done could be kept in it in book form.

Lesson 1.

Probably the best way to begin is by telling the class in story fashion of the epidemic in Yorkshire in 1932 (as in Holmes's book). Point out that this was due to germs in the drinking water. From that ask why we cannot dispense with water. By questioning make the children realize that water is absolutely essential to life and that there is no substitute. Ask where the water comes from. Pupils should be able to suggest the water cycle with a little help. The diagram given below should be copied and a short explanation supplied by the pupils themselves.



Why is there more rainfall over hills?

To illustrate evaporation mentioned above, have a distillation apparatus set up, with brine in the distillation flask, to represent sea water, and a flask to collect the pure distilled water. The Liebig condenser should be carefully explained to avoid confusion and misunderstanding. It is advisable to have an old condenser

which can be taken to pieces. Copies of the apparatus should be made in class while the experiment is in progress.

Homework (30 mins.)

A description of the experiment is to be written up, relating it to the water cycle. If there has been time for this in class, to stress the need for water, a letter could be written to a visitor from another planet to whom water is unknown, showing its fundamental importance.

Lesson 2

Deal with the different layers of the earth's surface. Set up two glass columns, one containing sand and the other clay. Pour water into each. Point out that one is permeable and the other impermeable to water, and that the water percolates through the sand. Thus underground lakes are formed. Limestone, chalk and sandstone, all allow water to percolate through. A diagram of the Thames valley illustrates this point very well.

Carry on next to Artesian wells and springs. Introduce river basins and rain gauges. Ask how one could be made, and set up a simple type, one pupil being made responsible for it. Talk for a short time on why rivers flow, waterfalls and the wearing away of river banks. Carry on to how we get our water, using as many pictures as possible to illustrate points made.

Historical approach

Originally all cities were built by rivers and people fetched all their water from these rivers. There were also water carriers called Cobs, who sold water to make a living. Owing to bad planning and sanitation, much illness was caused. Often refuse was put into the river at one point, and drinking water withdrawn further down the river. In the thirteenth century, water was stored in conduits, and people fetched it from there. Rich people had it taken to their houses through lead pipes.

In 1613 Middleton completed his work of cutting the New River. Pipes were made of elm trunks — point out disadvantages. Ask what we use now. Describe reservoirs and dams, showing as many pictures as possible. Draw diagrams of cross-section of dams, giving some idea of their great size. If possible make a model reservoir. By means of a funnel and a long piece of rubber tubing

put over blocks to represent hills, show that water will not rise above its own level. Thus if pumping is to be avoided, reservoirs should be situated on hills.

Homework

The experiment to be drawn and a description of it written up.

Lesson 3

Amplify work on reservoirs. Give out duplicated maps of the local catchment area, to be coloured and labelled. Deal with the transport of water to our homes, bring in pressure and simple ideas of gravity. To illustrate the former, have a tin with holes in it at various levels. Pour in water and notice that it spurts out with greater force at the bottom because of the greater pressure of the water. This should be written up.

Put cork in empty jar and pour in water. The cork rises owing to the pressure of the water on it.

Take a wide tube, open at both ends. Hold a card at one end, and put into water. The card remains on the end of the tube due to the upward pressure of the water. If water is then poured into the tube, the card will float away when the level of the water is the same inside and outside the tube.

Floating

The children should be given certain things to find if they float. Point out that it is the weight for size that matters, and thus lead on to density.

Homework

Experiments and explanation to be written up.

Lesson 4

Visit to nearest reservoir.

Homework

Essay on the visit.

Lesson 5

Discuss visit, emphasizing important points.

Talk about fountains and water wheels, relating it to previous work. Go on to pumps. Draw a diagram of a common pump on

the blackboard, and demonstrate its action. To be drawn and explained.

Go on to a discussion of impurities in water. Revise work on filtration. Recall the filter beds seen at the reservoir. Make a model filter bed and filter muddy water. (This to be drawn and written up.) This process, however, does not remove all impurities. Talk about fauna and invisible germs. Emphasize the fact that there are good as well as bad bacteria. Draw diagrams of certain types on the board. How can they be removed? Boiling and sterilization.

Practical applications

Fruit bottling and preserving. Antiseptics to kill germs, etc.

Experiments

Allow pupils to sterilize test tubes and corks. Put boiled milk into each. Leave one pure, put fly into another, a finger into another, etc. Seal and leave for a week. It will be found that all except the pure one have turned bad.

Growing cultures

Make a jelly with gelatine and meat extract or fruit juice. Pour into sterilized test tubes and cork up. Slant tubes and leave to set. Treat samples in same way as milk, and leave for a week. Colonies of bacteria will have formed on impure samples.

Homework

Experiments to be written up, a space being left for the results.

Lesson 6

Look at moulds. Finish off this section.

Remind pupils that although some impurities have been removed by filtration and others by chemical action, some still remain. By questioning introduce subject of solutions. The amount of time spent on this obviously depends upon previous work. Talk about hard and soft water very simply. If desired the pupils can be introduced to the technique of using burettes. Otherwise samples of water can be measured out and soap flakes added until a lather is obtained. This gives a quick, rough method of comparison.

Show methods of softening. Applications in the home. Occurrences in nature stalactites; and stalagmites.

Homework

Finish off the experiments. Trace the water pipes in your home, and find out as much as possible about the hot water system.

Lesson 7

Talk about the domestic hot water system. Describe convection currents by an experiment to show them, e.g. the action of heat on a flask containing water with a crystal of potassium permanganate in the bottom. Set up a model hot water system. Give out duplicated copies of a domestic hot water system, to be described and fully labelled and stuck into the folder. Describe the construction of a tap, how to repair the washer and avoid wastage. A duplicated copy of this can also be given out, or a simple diagram of it made by the pupils themselves.

Talk also of the ballcock in tanks and cisterns. Winter precautions.

Homework

Read about hot water systems, and revise experiments on the expansion of water on freezing.

Lesson 8

If possible show films on water, including:

‘The Water Supply’ (G.B.)

‘Water’ (I.C.I.)

Homework

Write impressions of the films, making a note of any specially good features and also any points not thoroughly understood.

Lesson 9

Discuss and criticize the films, amplifying points raised where necessary. Briefly revise the different aspects of water already mentioned. Animals need water in order to live, so what about other living things? By questioning bring up seeds and plants.

Experiments

Plant dry seeds in damp sawdust, and also soaked seeds. Notice the difference after a few days.

Examine roots, and notice that it is the hairs which take in the water.

Path of the water in the root

Put a plant in water containing red ink and leave for a week.

Label four leaves, 1, 2, 3, 4:

1. Smear on both sides with vaseline.
2. Smear the upper side with vaseline.
3. Smear the lower side with vaseline.
4. Leave untouched.

Hang up and leave for a week.

What is water? Obtain its physical properties by questioning. Collect all facts into a table to be copied by the pupils. Recall its solvent action, its action in the body, necessity for drinking it and the methods by which the body loses excess: excretion, sweating and breathing (this can be shown by breathing on a mirror).

If desired several periods can be devoted at this point to a consideration of the chemical properties of water, but it is probably better to omit it at this stage, unless the pupils are familiar with some chemistry.

Homework

Write up the experiments, leaving spaces for the results and conclusions.

Lesson 10

Look at specimens and draw conclusions from the results. Written experiments to be completed.

Mention leaf fall and ask why it is necessary. Talk about irrigation.

Primitive methods: the shaduf. Draw a rough sketch, and relate it to geography.

Go on to modern irrigation in India.

In the remaining time round off any unfinished topics, and mention any other subjects not previously covered.

Complete all written work and corrections.

Give out duplicated copies of the crest of the local water board.

Homework

Crest to be coloured and stuck on to the front of the folder. All written work to be put in order and fastened securely inside the folder, so that a complete record of the project is obtained.

At the early stages or with children of poorer intelligence a topic method such as we have given for C and D children (see pages 67-8) will probably be useful, but at a later stage and with intelligent children full use should be made of their capacity to 'establish logical connections and to see the 'wholeness' of the subject.

The 'unit plan' is popular in America. A term's work may represent one or two units,¹ and each of these may be split up into smaller lesson units. Such larger units might be: Man's food supply; Water; Houses and other buildings; Keeping healthy; Electricity and modern life; Fuels and heat. The last unit for instance, might be broken down to:

- (a) How things burn.
- (b) Fuels and how they are obtained.
- (c) Measuring and regulating heat.
- (d) Saving fuel.
- (e) Destructive fires: their causes, prevention and treatment.

¹ The methods may be studied in detail in the Smith and Trafton Series: *Exploring Science, Enjoying Science, Using Science*, published in U.S. by Lippincott and in *Modern Life Science* by Carleton Williams, issued by the same publishers.

CHAPTER VII

SOME OF THE CHIEF TOPICS IN THE SCIENCE COURSE

IN this section we propose to deal separately with the main topics which will normally find their way into the science course of schools for children of eleven to fifteen or sixteen years of age. For the sake of simplicity we have separated the subjects but the teacher will appreciate that science should be taught as a whole, and remember that in the past the conception of science in schools has suffered through an unnecessary narrowing of its scope and a careful and artificial separation of its various subjects. Not every school will deal with all the subjects we mention even in a descriptive and general manner, but a much broader scheme could be adopted than is at present the case. Many schools are now able to find a total of 180 minutes a week for the science teaching, provided that this includes some hygiene. The average at present would appear to be a total of 100 to 200 minutes each week. Sometimes time can reasonably be saved by correlating some parts of the science course with other subjects such as mathematics (physical measurements), geography (geology, meteorology, astronomy), citizenship (hygiene). In any case, it is better not to attempt too much, especially with C children, but rather to foster enthusiasm, encourage observation and reading, and to apply the work to life.

General Physics and Mechanics

General physics is usually understood to include all that is left over when the other topics in physics have been assigned to electricity, magnetism, heat, light, or sound. In the past the important branch of science known as 'properties of matter' has suffered by being dry and pedantic and far too mathematical. Also, the stress was put on the wrong aspects of it. It is far more important for the pupil to know something of surface tension which finds many an application in biology, the study of soils, and in domestic work, than it is to have a knowledge of the use of a micrometer gauge.

The Metric system of measurement must be a part of the child's equipment, and if this is not done by the mathematics teacher, the science master will perforce have to undertake it. If this task is done practically and with reference to its history, it will not prove long or difficult. Moreover, the child should be led to see that in the end it will simplify his work very considerably. A glance, for instance, at accounts of the classical researches of Dr. Black of Edinburgh on alkalis will show the heartbreaking clumsiness of the English weights and measures system when used even for very simple quantitative investigations.

Much has been made in the past of a multiplicity of methods for finding specific gravity. The idea of density as a useful quantity can be developed quickly from personal experiment. Densities should be estimated by holding various objects in the hand, and good spring balances both of the 'push' and 'pull' variety will be accurate enough for weighing the objects used. Fairly wide diameter measuring cylinders holding 500 cc. will serve for giving the volumes. Specific gravity is a special case of density and care should be taken to see that the word 'specific' is not abused. Some general experiments can be done to show that pieces of lead and 'silver' and bronze coins float on mercury. Gold and platinum are much more dense than lead and mercury. (Do not drop a clean gold ring or coin into mercury or it will become covered with a film of amalgamated mercury which is exceedingly difficult to remove.) Common objects should be selected for density determination — coal, marble, dry earth, wood, a piece of meat, a piece of bone. Some things float because of the air they contain; sometimes even prepared chalks or pumice stone will float.

Medicine and other fairly large graduated bottles may be used for density determinations of liquids. A simple hydrometer may be constructed from a narrow test-tube, a few lead shot, and a piece of paper. Its use in finding the density of milk or accumulator acid, etc., should be shown. (Some 'wireless' accumulators have all sorts of ingenious devices to show the density of the acid, for when the accumulator has 'run down' the acid has become more dilute owing to the combination of oxygen and hydrogen from its plates.)

Many children find the Principle of Archimedes difficult, but it

becomes perfectly simple when we think of the flotation of pieces of wood and ships on water or of balloons in the air. The salinity of water in a glass jug may be adjusted so that an egg will neither float nor sink, or aniline may be used (slightly coloured if necessary), and it will assume a spherical shape; or again we may consider why we can float in water. A good way to illustrate the Principle of Archimedes is to make a large displacement can from a three-gallon watering-can by turning the spout downwards, and resoldering it. This may be filled and stood on a large domestic spring-balance and a piece of rock weighing perhaps 20 lb. carefully lowered into it while being suspended from a tension balance, and the overflowing water caught and weighed in a vessel standing on yet another spring-balance. The balance on which the can stands shows no change, the balance from which the rock is suspended shows a loss equivalent to the gain in the third.

The idea of pressure and its transmission can be illustrated by simple experiments and examples from everyday life. The pressure of the air may be shown by collapsing a large thin metal can. Many of the older experiments for showing transmission of fluid pressure are still acceptable. The Bramah Press, hydraulic jack, and pneumatic and hydraulic machinery are not yet obsolete. The pressure of a column of water is easily shown, and all children will have heard of the troubles which beset divers and caisson workers. This will lead to a consideration of the barometer, various kinds of pumps, the flushing cistern (automatic and hand operated). The collapsed tin gives a starting point for a discussion of the aneroid barometer and its uses. Its functions as an altitude measurer are easier to explain than as a weather forecasting instrument, for it will not be clear to children at this stage why the barometer goes down in damp weather when it seems to them that water vapour has been *added* to the air.

Matters connected with pumps are by no means as old-fashioned as many think, and the intelligent child will be fascinated to read about and experiment with such things as simple rotary blowers and pumps, force pumps, and automatic hydraulic rams for lifting water. Although time does not permit much study of it there is a very large practical field which can be developed from these subjects without much difficulty.

Surface Tension and Capillary Attraction

With the aid of a demonstration lantern or an episcopo experiments on these subjects may be rendered visible to a whole class. Many of the experiments may be performed by the child at home. The experiments with the camphor or soap boat, needle floating on water, a hot needle plunged into water which has been covered with a fairly thick dry layer of lycopodium powder are well known. The skin of water and its effects are interesting and have important applications; for example, pouring oil on water in choppy seas, and killing mosquito pests by application of paraffin oil to the surface of the water in the swamps in which they breed (see p. 36).

Capillary attraction is easily demonstrated. It has widespread application to botany and zoology, the dampness of linen clothes, moisture in soil, blotting paper, certain methods of lubrication, etc. The explanation of capillary attraction is not difficult provided the idea of a stretched skin is grasped, aided by the very simple mechanics of the triangle of forces.

There is a variety of further topics in general physics with which some teachers may like to deal. Edser's *General Physics*, which avoids anything but simple mathematics, is still of use to teachers because it supplies some practical examples not usually found elsewhere.

Mechanics

No useful purpose is served in the early stages of the study of mechanics by defining force and mass. At all stages these are real difficulties and it is better to let the conceptions grow out of the child's experience. There is an early tendency to fail to distinguish between force, work, energy, and power, but when a few experiments are performed and thought about, the differences become apparent to most children even without mathematics. Girls are quite interested in mechanics if the subject is not made too mathematical. As a basic point of the physics course is a conception of energy in its various forms, the work in mechanics should lead up to later studies in heat and electricity.

A convenient way to begin the study of mechanics is to deal with machines and work. Machines were used even at a time when all applied motive power came from man and animals. Thus the first

machines were levers, pulleys, and inclined planes, in order that large weights could be moved by men or animals. The heavy weight moved a small distance but the men who pulled on the rope or lever had to move a much greater distance. These machines did not create work, they only made it more useful, indeed in the process of doing this some of the work was lost, the energy being changed by friction into heat. We can exert forces without doing any work. Work is only done when the force moves and it can be measured by multiplying the amount of force by the distance through which it moves. An idea of this can be gained by lifting weights vertically, or dragging a heavy object over a horizontal surface. That energy is wasted by friction needs no explanation, but some experiments are necessary to show how efficiency may be improved by reducing friction. The use of lubricants and ball bearings in various machinery and jewelled bearings in watches are examples which are at once apparent. 'What happens when bearings run hot' will give a clue to the idea of heat as a form of energy, and the form which most often appears when friction is the cause of the transformation. This will give the brighter children a glimpse of the idea of the conservation of energy and how it may be measured in its various forms. The simple machines such as pulleys, levers, screw jack, wheel and axle can easily be made or purchased quite cheaply, and an ordinary bicycle will act as a basis for many experiments on mechanical principles. There is no need to spend time on the three classes of pulleys, for the block and tackle (Class II) will suffice and a child whose enthusiasms take him further than this, will find that a set of Meccano parts will occupy him for a long time.

Levers can be thoroughly understood by referring to their applications and the principle of moments is so simple that a child will readily grasp it by experimenting with a model 'see-saw' and weights. The time-honoured applications of the three classes of levers are still interesting but many more will occur to both teacher and pupil; for example, the action of various muscles and joints relate the work to hygiene, a piano key action gives us examples of the three classes working together, and there are hundreds of examples in structures, bridges, cranes, roof trusses, etc., where the principles of moments apply, but the 'levers' do not move. The

boy who uses his Meccano set and the Boy Scout who builds temporary structures such as derricks will be able to supply many examples. The triangle of forces also becomes easy if it is approached through its applications. The tension in a picture cord may be demonstrated, and it can be shown that when the angle which the cord makes with the top of the frame is made small by shortening the cord the tension increases; indeed, by using thread instead of cord, matters can be adjusted so that the thread is strong enough to hold the picture at first, but will break in the second position.

'Centre of gravity' can be developed from the simple principles of moments and a few general experiments can be done to show its importance. Those on balancing and stability are very acceptable to children as they endeavour to interpret them in terms of their own bodily sensation.

Acceleration is a matter of difficulty for many children, but a demonstration with falling treacle which gives a slow-motion impression of a body falling under gravity is useful, and a little thought will show children that vehicles, such as trains and trolley buses, attain their speed gradually by acceleration, and that 'jerks' are not instantaneous increases of speed but rather accelerations during very short periods of time. That the more gradual acceleration requires less force to produce it is illustrated by the fact that when a motor car starts with a jerk the engine is frequently stopped thereby.

A variant of the 'old guinea and feather experiment' to show that all falling bodies have constant acceleration can be performed by fixing two small electromagnets energized by the same circuit to the ceiling, and allowing each to hold a ball, one of steel and another of wood with a few iron nails driven into it. On interrupting the electric circuit both balls fall to the floor, reaching it simultaneously.

Kinetic and potential energies are easily illustrated by thinking of a boulder balanced on the edge of a cliff and then pushed over, or a pendulum swinging. This will lead to a study of various other forms of energy and how they are all related, how we can store energy, or transform it so that it can be transmitted from one place to another, and how energy comes from the sun and from

the rotation of the earth. As the other branches of physics also deal with energy this will give a convenient point of contact with them.

The pendulum and the gyroscope are two useful pieces of apparatus for mechanics and general physics experiments.

The pendulum

Potential energy converted into kinetic energy. The discoveries of Galileo and Huygens. Clock pendulums. How they are made to keep time. How gravity affects pendulums. Foucault's pendulum and the rotation of the earth.

(A Foucault's pendulum may be set up in a lofty school-hall and will show the motion of the earth. It can be made to act as a clock for an hour or two.)

The gyroscope

(Gyroscopes, sufficiently sturdy to demonstrate all the principles of 'spinning tops',¹ may be bought for a few shillings; a heavy wheel rotating in good bearings and driven by a small electric motor is admirable.)

The properties of a spinning top.

The gyroscope used for stabilizing purposes.

Gyro compasses and their uses.

Power²

Just as we may regard work as force \times distance we may think of power as force \times speed. The child will appreciate that even he could raise a ton of coal from the cellar to the top of a house if he were given plenty of time, but a steam crane would do the same work very much more quickly. It would have more power. The idea of a Horse-Power can be grasped by thinking of a heavy boy weighing eight stones being raised about five feet per second. Many boys can 'put on a spurt' and go up-stairs at a rate of five feet per second (considered vertically), but normally they could not do much more than $\frac{1}{4}$ or $\frac{1}{8}$ H.P. for long. As power varies with speed, the problem with regard to engines and cars is at once apparent. A $3\frac{1}{2}$ H.P. motor-cycle when going slowly may give

¹ See Perry's *Spinning Tops*.

² An excellent series of booklets on power, its nature and use may be obtained from General Motors, Detroit, U.S.A.

only 1 H.P. or less, but when going quickly it may yield 12 or more Horse-Power. In petrol engines nominal Horse-Power simply refers to the capacity of the cylinders, each 100 cc. being reckoned as the equivalent of a Horse-Power. As friction owing to air resistance increases enormously as compared with velocity at great speeds, many more Horse-Power are often needed to make a racing car or aeroplane go even a few miles per hour faster. The lessons on mechanics should also give an elementary treatment of the problems of flight and how aeroplanes are designed. The limitations of the air screw as a means of propulsion, and the development of jet engines will prove to be interesting and useful topics.

Mechanics finds some useful examples in elementary physiology: the action of the muscles, the structure of the bones, and the way the stresses are distributed about the body, heat and mechanical energies, etc. Sir Arthur Keith's book, *Engines of the Human Body*, should be read in this connection.

Here, the descriptive side of mechanics has been stressed, as the quantitative aspects — important though these are — have been overworked in the past.

Class Reading

'Things around us.' Chapters ii, iii, iv.

'Science and Life.' Chapter ii.

Heat

Heat will figure in any science course whether it is the normal one of general interest, or if it has a bias to rural or domestic studies. Even very simple work, which will be necessary with C children, will deal with heat in connection with life in general and the human body in particular. This leads to a discussion of hot and cold days, clothing and the exchanges of heat, how heat is transferred and what we can do to keep ourselves and other things warm. At the elementary stage it is quite sufficient to consider conduction, convection, and radiation through their applications. A discussion of the suitability of various types of clothing, green-houses, fires of various types, Thermos flasks, will raise questions which deal with the modes of transference of heat and in addition will suggest avenues which will lead to other inquiries. For in-

stance, the idea of suitable clothing is not exhausted when conduction and radiation are dealt with, and a consideration of artificial heat at once raises the question of electricity, combustion, etc. The production of heat from the burning of coal, wood, petrol, and simpler chemical substances will be compared with the process of 'combustion' of food, and to the rural child this leads to a consideration of the danger of ricking damp hay and straw, and the steaming of manure heaps. With older and more intelligent classes the idea, to quote the title of Tyndall's great work, of *Heat, a Mode of Motion*, that is to say, a form of energy, should be the aim.

Frequently in the past useful time has been wasted in teaching heat by too many formal experiments on specific and latent heats, water equivalent, expansions mathematically considered, thermometric scales and the making of thermometers in the laboratory. An introduction to the subject could start with a consideration of the way in which heat is produced, and how it appears in the place of some other form of energy.

(1) Heat from Mechanical Energy.

- (a) Rubbing a button on the desk.
- (b) First action in striking a match.
- (c) The water of Niagara Falls is warmer at the base of the falls.
- (d) Heat and sparks from friction, etc.

(2) Heat from Electricity.

- (a) Electric fire, lamps, irons.
- (b) Conflagrations due to Lightning.

(3) Heat from Light.

Light falling on a dead black surface disappears but the surface is warmed up. Men wear white suits in the hot sun.

(4) Heat from Sound.

Sound is absorbed by cushions, blankets, and soft materials, but in the process they are warmed up but only very slightly as a great deal of sound is equivalent to only a little heat.

(5) Heat from Chemical Energy.

- (a) Burning of coal.
- (b) Digestion of food.
- (c) Final action of striking a match.
- (d) Self-heating soups.

Heat seems to be the ubiquitous form of energy and the 'graveyard' of the other kinds. The kinetic energy of a bullet changes to heat when it is suddenly stopped by a target, the energy of the meteorite changes to heat by the friction of the atmosphere and the meteorite becomes incandescent, appears as a shooting star and not infrequently it is disintegrated to dust. Electricity fritters down to heat in a resistance wire, and light and sound absorbed by suitable substances turn up in equivalent amounts of heat. The enormous potential energy of the water in the river above the cataract of Niagara turns into kinetic (still mechanical) energy on the way down, a little of it is tapped off and rotates turbines, which in turn actuate dynamos which supply heat, light, locomotion, work wireless sets and other electrical instruments in the town of Buffalo some distance away, but the greater part of the energy seems to lose itself in the pools below. However, it is not really lost for a thermometer will show that the temperature of the water after being churned in the river at the bottom of the falls is a measurable fraction of a degree above that in the river at the top. A great deal of heat has to go a long way and therefore the net result in increase of temperature is very little. The energy is all there but it is not in a useful form. We gather that if there is sufficient difference in temperature levels, or the equivalents of these levels in other forms of energy, we can obtain useful work, we also see that these temperature and other levels show a tendency to come closer, and with their gradual approach the available energy in the universe is becoming less. Here is a convenient starting point for a discussion in later years of the problems of energetics, entropy and heat cycles in engines.

The idea of temperature as distinct from quantity of heat is important. The unreliability of personal estimates of temperature shows the necessity of thermometers and other instruments for measuring it. Analogies to show the relation between temperature

and quantity of heat are useful but must not be pushed too far. The hydrostatic analogy is safer at this stage than the electrical one, but the latter is an interesting connection with another aspect of energy. If the idea that energy is never lost is firmly grasped there is no difficulty in understanding temperature levels and quantity. There is no need to spend much time on thermometry. The different types of instruments used by gardeners, doctors, meteorologists, and in schools should be mentioned. The relations between the Centigrade and Fahrenheit scales are at once obvious if a large drawing of a thermometer is graduated from freezing point to boiling point with one scale on each side of the stem. The idea of capacity for heat and specific heat are easily grasped and experiments should be done on a larger scale than was usual with the small copper calorimeter. Calorimeters gain from being suspended in large polished tins, but quite large tins will serve instead of the traditional calorimeters and they lose very little heat by radiation. There is no advantage in packing calorimeters in cotton wool. One of the most accurate determinations of the specific heat of a metal in school was done using a brightly polished pewter teapot instead of the calorimeter! There is something magic about the word 'calorimeter' which is apt to be misleading and all the usual heat exchange experiments gain by being performed on a much larger scale. The water used can be measured out quickly and a rough weighing of the other materials will suffice. Expansions by heat may be taught through their applications. The phenomena of change of state are most important. It is not enough to deal with ice, water and steam. The phenomena of expansion or contraction when a liquid solidifies have important applications, as in casting type metal or iron. Carbon dioxide in the solid state is easily obtained from ice cream depots, and liquid air and other gases can be supplied in many districts. Conduction of heat can be treated very quickly and simple experiments will suffice to show that different substances conduct heat at different rates. Very poor conductors or heat insulators have wide application in daily life. Convection is important as it is related to ventilation, winds, central heating, etc. Radiation is even more important because it is the means by which the heat of the sun reaches the earth. Heat can then be compared with light. The radiation of the heat of the

earth at night leads to a consideration of the formation of dew, and hoar frost in winter. The conditions for good radiation and good absorption of heat have wide application to clothing, domestic heating, gardening, zoology. Experiments on the rates of cooling of two identical vessels, one blackened and the other polished, each containing the same amount of hot water, will illustrate this. A thermopile is very useful for studying radiation, and it can be made for a few pence. (A small cylindrical helix of German silver wire 2 cm. long and 1 cm. in diameter is lowered into copper sulphate solution so that half of it is immersed, the axis of the cylinder being at the level of the liquid. Copper is thus deposited on half of the wire. The junctions of copper and German silver on one side are blackened and mounted in a tiny wooden box so that the blackened side faces outwards. A small cone of tin-plate should be fitted to the front to give the instrument directional properties, and the ends of helix should be brought out to two terminals. Such an instrument will give excellent results with a mirror galvanometer made with a magnet from an old magneto.)

Heat engines of various types will be a most important part of the work. The subject may be developed historically from the days of Hero's 'turbine': beam pumping engines depending on the partial vacuum caused by the condensation of the steam: Watt's modifications of the engine, using pressure steam, D valves, and various other improvements; the gas engine, the petrol engine, and the development of the automobile and aeroplane. Modern steam turbines and their applications will be discussed. A simple treatment of gas turbines and jet propulsion engines, with some ideas concerning the problems of design and materials which have to be dealt with, is interesting and important. The suitability of the various engines for different purposes will serve as the basis of a useful discussion. In order to connect the work on engines with mechanics it is well to mention the question of efficiency. It must be remembered that some machines often seem efficient because of their convenience, although mechanically speaking their efficiency is not great. Gramophones, typewriters, sewing machines are physically not very efficient, and this applies to electric light bulbs which give more heat than light energy.

The mechanical efficiency of the steam engine is thirteen per cent or less, that of petrol and gas engines twenty per cent, whereas electric motors and transformers have an efficiency of ninety per cent or more.

The laws of thermodynamics and the idea of entropy are outside the scope of secondary school work, but there is no better approach to them than through an understanding of the energy changes in the cycle of the simple heat engine.

Topics for Science Societies

Turbines.

Aeroplane Engines.

Pyrometry.

Liquid Air.

Diesel Engines.

Refrigerators.

Jet propulsion and gas turbines.

'Fido' and fog clearance.

Heat and ventilation in house design.

Some problems of the economical use of fuel.

Class Reading

'Science and Life'. Chapters iv and v.

Light

The treatment of this subject was formerly spoilt by dull lessons on simple geometrical optics, with practical work largely confined to 'pin methods' with slips of mirror, glass blocks, and prisms. A moment's thought will show that the applications of the study of light to everyday life are not only widespread, but are elegant and beautiful as well. Without indulging too freely in 'projects' it is possible to construct a useful course in light merely through its applications to simple optical instruments. The importance of vision to us provides a starting point which gives the idea of light as a radiation by which we can see. Everyone uses a camera, indeed they may be purchased in parts at the sixpenny stores; the cinema, lantern, and episcopo are well known and frequently available in schools. Mirrors, spectacle lenses, binoculars, non-reflecting shop windows are met with everywhere, and the Ost-

wald colour system has provided a sound physical¹ basis for teaching what was often a strangely neglected topic both in science and art lessons. Effects depending on light form the basis of a large number of entertainments and advertisements. Ultra-violet light (which strictly speaking is perhaps not light at all) has useful physiological and chemical properties, whilst infra-red rays, which again cannot be seen by reason of their longer wave lengths, can be used for penetrating fogs and taking clear photographs through London mists.

Whether light is really 'waves in the ether' or 'discrete quanta' is beyond the scope of secondary school work, but the idea of 'waves' is certainly a useful way of comparing it with other forms of energy. The simple radiation spectrum which shows the changes in properties of the 'ether waves' as they increase in length makes an interesting chart for the science room. As the wave length increases we have X-rays, ultra-violet rays, the visible spectrum, infra-red rays, heat rays, and finally wireless waves which may reach miles in length.

The early work on the propagation of light need not detain us for long. That 'light travels in straight lines' is broadly true and is evident from the simplest of observations. The pin-hole camera presents an easy method of showing this and incidentally it reveals that this generalization can be very misleading at times. The phenomenon of diffraction is hardly within the scope of this early work but intelligent children will naturally want to know why there are colour patterns when the eye receives light from the surface of a gramophone record at a glancing angle and in other everyday phenomena of a related nature such as the colours of thin films of oil on water. Almost any small 'light-tight' box which has been coated black on the inside will serve as a pin-hole camera. In a dark room, a small plate ($2\frac{1}{4}$ in. by $3\frac{1}{4}$ in.) can be fixed to the back of the box with the emulsion side facing the front, the box is then closed (using black adhesive tape to obscure any chinks of light) and a hole is made in the front with a needle. (If the front

¹ It must be appreciated that questions of colour are largely subjective and that the psychologist and artist have at least as great a claim for consideration as the physicist in matters concerning colour. We are reminded of Goethe's criticism of the Newtonian theory of prismatic colours: 'Friend, beware the darkened chamber where they twist the light for you.'

is of thick material a hole of about $\frac{1}{4}$ in. diameter should be cut in the centre of it. This is covered with a piece of black card in which the pin-hole is made.) Suppose that three similar pin-hole cameras with 'pin-holes' which differ in diameter are exposed on the same subject. A coarse darning needle will serve to make the hole in the first, an ordinary pin the second, and a fine sewing needle the third. Exposures will vary, but as the modern plate has enormous latitude considerable errors in exposure will not ruin the results, and one minute for the first, five minutes for the second, and twenty minutes for the third will suffice in bright or sunny summer weather. After development and fixing we find that the first camera has yielded results with poor definition, there is an improvement in the sharpness of the picture in the second, but in the case of the very fine needle hole the picture is even more poorly defined than that obtained with the coarse darning needle! The statement that light travels in straight lines, which is the basis of that very artificial study — geometrical optics, is only true when a fairly thick beam of light is considered; it will serve for the elementary treatment of reflection and refraction, mirrors, prisms, and lenses, but it may bar progress to later work unless it is qualified. Some interesting experiments on diffraction are given in Preston's *Light*. A silver threepenny piece suspended in a dark room at a distance of 12 feet from a pin hole acts as though it were transparent, at first sight. It will throw an image of the pin hole on a screen 12 feet away from it.

The idea of 'electromagnetic waves' is outside the scope of the work, and in any case there is yet no real reconciliation between the 'wave' and 'quantum' points of view, but if the idea of waves and wave lengths has been grasped some connection between the various forms of radiation is easily seen.

A wave trough will show practically all the wave effects and will explain at once many simple mechanical, optical, and acoustical phenomena. This apparatus is easily made by taking a glazed window frame, about 2 ft. by 3 ft. or larger, and standing it on two trestles so that the glass of the window forms the bottom of a horizontal shallow trough supported only at its two ends. Water is poured in to a depth of $\frac{1}{2}$ in. to $\frac{3}{4}$ in. and a 'point' source of light is placed on the floor. A motor headlight bulb or 'point-o-lite' is

admirable, and the light can be enclosed by draping the trough from its sides and ends to the floor with black material such as old university gowns. The room is darkened, and projected on the ceiling will be seen a rectangular patch of light, all of which has been transmitted through the water, on which any disturbance at once becomes apparent. By using a smaller trough (which is not recommended) and a large mirror at forty-five degrees the light may be projected on to a vertical screen, which saves the slight inconvenience of having to watch the ceiling. (Astronomers very often have to recline to make their observations, so even with the first method we are not in bad company!) The waves can be generated by tapping the surface of the water with the edge of a small ruler. Refraction through rectangular blocks, prisms, and lenses may be shown by placing in the water pieces of glass or other material about $\frac{3}{8}$ in. thick which will rest on the bottom of the glass of the trough, in shape like sections of the block, prism, or lens. These render the water more shallow and bend the waves at their edges in a very striking manner.

It must be remembered that these are merely demonstrations, which must not be pushed too far, and they quite fail to show some of the properties of transverse waves (for example, polarization). The wave trough is useful as it provides a good background when the simple work on prisms and lenses is undertaken. It is, of course, necessary to obtain some idea of the physical constants commonly used in optics. It is much more interesting to follow the path of a narrow beam of light by rendering it visible, than by the pin methods. Fluorescent glass, water to which fluorescein has been added, and cylindrical lenses are useful for refractive index experiments. For lenses the path of the light can be seen by cutting a lens in half along a diameter and glueing it to a piece of white card held in a vertical position.¹ The source of light can conveniently be a twelve-volt lamp enclosed in a small blackened cigarette tin in which slits have been cut. By adjusting the position of the light, rays from it can be made to fall at a very small angle on the cardboard to which the half lens is fastened, and the course of the light will clearly be seen. This method is applicable to reflections and refraction at various surfaces. The simple lens

¹ Mr. F. W. Meier's adaptation of this is cheap and serviceable.

laws can be proved by using an optical lantern or an old-fashioned camera with ground glass screen. The body of a 'Universal' lantern can be made from sheet tin or iron in the handicraft shop, and condensers, slide carrier, objectives can be added as desired in separate mountings which can be made of wood. An arc lamp is not necessary, though it is interesting to make one, but a flat filament lamp consuming 250 watts upwards will give admirable results. The 'Universal' lantern is well worth acquiring; it can be used for experiments on lenses, prisms, and colour. By fixing a slide carrier to the front of the condenser mounting it makes a useful projection lantern, and by the addition of a prism, a sheet of glass, and a mirror it can be used for projecting objects and small experiments placed horizontally. An expensive lantern must be considered a luxury, but even in the case of the improvised or home-made article it is worth while to invest in a good objective (a remark which applies with even more force when buying or making an episcopo).

Colour is one of the most striking and useful aspects of the study of light and it has had inadequate treatment in the past. With the advent of the Ostwald colour system, which is now the sound scientific basis of colour teaching in art lessons, we have at once an interesting correlation with another subject. The old method of making green from blue and yellow, and purple from blue and red when using pigments, was a subtractive process only possible because of the lack of 'purity'¹ of the original colours, and naturally resulted only in muddy greens and purples. The work of Newton and, nearly two centuries after him, of Tyndall and Maxwell on colour, is still very useful, but with the development of colour filters now made very cheaply for use in photographic work many simple and beautiful experiments may be devised.

A spectrum can be produced by using a projection lantern or other enclosed strong source of white light, limited by a narrow vertical slit (an adjustable slit may be easily made in the metal workshop). Light coming from this is allowed to fall on a prism and by means of a lens the spectrum can be focused on a screen. The prism should be made of heavy or flint glass of good dispersive power; or a hollow prism or prismatic bottle (optically worked)

¹ Purity in the spectroscopic sense.

may be filled with pure carbon-bisulphide. The old idea of seven colours of the spectrum should be carefully avoided as every vertical line of the spectrum represents a pure hue. Gelatine filters of various colours (which may be rendered permanent by mounting between two glass plates) can be inserted in the beam either in front of or behind the prism and the effect on the spectrum is noted. The nature of the colour of a transparent substance, that is, the constituents of transmitted white light which it does not absorb, is easily shown. It is also noted that nearly all colour filters, even blue ones, pass varying amounts of red light.

There are many simple ways of 'compounding' colours by addition, but no better way can be found than that of superimposing the colours by projecting them on to a white screen in a reasonably dark room.¹

The three colour theory of colour vision is not difficult to appreciate and may be illustrated very easily by certain processes of colour photography such as the Dufay where a tricolour 'latticed' background (or 'réseau') is used behind the emulsion. By means of a low-powered microscope or micro-projector it will be seen that this lattice is divided up into small squares of blue, green and red. A white patch on the film will be seen to be made up of a mixture of these three colours; a yellow object, the image of a daffodil for instance, is yellow because green and red light are allowed to pass, and so on. This subjective or 'psychological' colour mixing, as it is sometimes called, can be shown by having three electric light bulbs in separate boxes with green, blue, and red windows respectively. If these are placed near together in a straight line, each illuminating the same screen, the effects of colour mixing can be seen by interposing a solid object between the coloured lights and the screen and observing the colours of the illumination of the three shadows; or alternatively three small lenses fixed in a circle of wood and each backed with a different colour filter may be used with the 'Universal' lantern to cast overlapping coloured images of a circle of white light coming from the condenser. Where the three circular images overlap a patch of white light will be seen if the colours are green, blue, and red; and the other

¹ See also the experiments due to Sir Graham Savage, C.B., in *The Science Master's Book*.

usual additive colours may be observed where only two images overlap. The subtractive method of producing colours by the superposition of the secondary, 'minus' or subtractive colours (yellow, magenta and turquoise) can be exemplified in the technical process and the Disney films.

A most important part of the work is a discussion of the working of the common optical instruments. An old type of bellows camera with focusing screen will not only serve to explain the action of this instrument of everyday life, but from it the lens laws may be derived, and aberration and distortion shown; and the necessity of a compound lens for correcting these shortcomings of single lenses will be evident. The iris diaphragm and the action of a small 'stop' in sharpening the image cast by a cheap lens are worth noticing. The difference of focusing in the camera and in the eye (the one by 'racking' the lens in and out and the other by bulging or flattening the lens itself) is useful to note, and the 'portrait attachment' of the box camera may be compared with a spectacle lens used in front of the 'long-sighted' human eye. Telescopes and microscopes for demonstration purposes can be made from quite cheap lenses (two for each instrument) fixed into cardboard tubes.

Optical instruments supply the tools and measuring instruments on which scientists depend in other fields of investigation. The work of the bacteriologist and botanist would be impossible without the microscope, and the astronomer would have to limit himself to very elementary and general observations without the telescope; the mariner needs the sextant and the physicist and chemist find the spectrometer and polariscope indispensable to their work. Without lenses we could not have opera or field glasses, the cinema, cameras, and many other things. The history of the subject is very fascinating for it is seen that the discovery of telescopes, microscopes, and spectroscopes opened the door at once for immediate new discoveries. In astronomy and certain branches of biology these discoveries may be likened to the case of a boy who struggles on, trying to make things by using an old pocket knife, and is suddenly presented with a box of tools.

The British Journal Photographic Almanac, published annually, provides a mass of information on lenses, films, cameras, colour,

chemicals, etc., which can readily be applied to science teaching in light and chemistry. The *Ilford Manual* is a standard work on scientific photography.

Topics on Light for Lectures and Demonstrations to Science Societies

'Colour photography, including technicolor films.'

'Moving pictures and how they work.'

'Testing eyes.'

'Giant telescopes, how made and used.'

'The microscope and how to use it.'

'Colour vision.'

'How to improve your photography.'

'Ultra-violet light and its effects.'

'Photo-electric devices.'

'Optical illusions.'

'How lenses are made.'

'Lighting houses, schools, and factories.'

'The science of seeing.'

If an expert cannot be found to talk on these subjects, they can be set as 'lecturettes', and senior pupils selecting one each can prepare it by reference to various books, doing experiments, and asking questions to people who are likely to know.

Class Reading

'Things around us'. Chapter iv.

'Forces at Work'. Chapter iv.

'Science and Life'. Chapter iii.

An excellent history of optics in coloured plates is published by Bausch and Lomb of Rochester, New York.

Sound

Sound is the Cinderella of the branches of physics and very often all work in it is neglected. Lack of time will militate against any full treatment of the subject and in some cases it will have to be omitted altogether. However, there has been a great revival of interest in acoustics during the last decade owing to the application to things which are now commonplaces in our lives, and these have developed largely by the use of electrical methods. The wireless 'loud speaker', the sound film and sound camera, 'acousti-

cal' and 'electrical' gramophones and recording, are rather advanced aspects of the subject, but simple explanations will suffice. Sometimes, indeed, the more recent developments are easier to understand in that they give further opportunities for the study of electricity and magnetism. A simple account of the problems of the 'acoustics' of buildings including reverberation and echo is long overdue, for the practical side of this question has been grossly neglected.

Many boys will have read about submarine signalling, aeroplane detecting, automatic depth finding (sounding) at sea, and they will be interested to extend their knowledge to some of the simpler aspects of ultra-sonics (very short sound waves above the range of audibility) which can be directed in the form of a beam, will cause violent disturbances in a beaker of water ultimately boiling it, will kill small animals, and can be used for sterilizing milk without destroying its vitamins. These waves are usually generated by a valve-operated quartz-crystal, but a piece of nickel-iron can be used in the place of the quartz, but the waves are not so small. The formal treatment of sound never need be taken in a senior school, indeed it is sometimes neglected in advanced physics courses — rather unjustifiably, we think. As regards 'pre-electrical' acoustics a simple treatment of the generation of sound waves and their propagation is not too difficult. A thorough treatment of wave motion which demands considerable mathematics is out of the question, but simple ideas arising from experiments with wave troughs, long coils of wire, a rope held in the hand and shaken, and a stone dropped into a pond, etc., will be useful because they show a general method of transferring energy. The consideration of the production of sound in the violin and pianoforte and other musical instruments gives a direct application of this work to another school subject. This can form the basis of the consideration of a musical note, its pitch, loudness, and quality. If an organ is available in a nearby church or concert hall it yields many possibilities in such things as resultant tones, nodes, the compounding of complex tones from the simpler constituents, etc.

A study of the ear and hearing at once links this work with hygiene. Sometimes, it is only through hygiene and physiology

that sound receives any consideration at all. Even if time does not permit the giving of many lessons on sound it will form the basis of a number of lectures and demonstrations at science society meetings and wireless clubs. Such questions as 'Vibrations' (introducing the tracing of various harmonic patterns), 'Loud-speakers and gramophones', 'How the Talkies work', 'The instruments of the orchestra', 'Short sound waves and their uses', will provide topics for such demonstrations, which can be supplemented by reading the ever-growing literature on the subject.

It is possible to arouse interest in the subject of sound without going further than a cheap gramophone record, a low power microscope, a variety of needles, a turntable, and 'pick up' or ordinary acoustical soundbox. At the end of a single lesson children will grasp that:

- (1) Sound is vibratory in origin.
- (2) That amplitude and loudness are related.
- (3) Pitch and the number of vibrations in a given time are connected together.
- (4) That different qualities of sound come from differently shaped vibration patterns.

When curiosity is aroused we find children experimenting for themselves, and playing the record by holding a gramophone needle between their teeth and keeping it in the revolving groove (this requires a little practice), by driving the needle through a piece of card which acts as a sound box, and by using other improvised sound boxes and horns of different shapes. From these 'amusements' they will gather enough material to form the basis of a number of lessons. That the older type of acoustics can be treated in a manner which is at once simple and fascinating is shown in one of Sir Wm. Bragg's series of lectures given during the Christmas holidays in the Royal Institution, and which were subsequently printed in his book, *The World of Sound*.

For further reading by the teacher:

The World of Sound, Wm. Bragg.

Hearing in Man and in Animals, R. T. Beatty.

Talking Pictures, B. Brown.

Acoustics of the Organ and Orchestral Instruments, E. G. Richardson.

Science and Music, Jeans.

Planning for Good Acoustics, Bagenal and Wood.

A Fugue in Cycles and Bells, Mills.

The Physics of Music Wood.

A Short Course in Sound

How Sounds are Produced

(1) Vibrations of various types.

(2) Noises and violent disturbances.

(The distinction between musical sounds and noises is one which it is increasingly difficult to make as the matter is a subjective one, but on the whole musical sounds arise from more regular and less violent vibrations.)

Apply to loud speakers and gramophone soundboxes.

How Sounds Travel

The transference of energy by waves — application to other forms of energy. Echoes and reverberation. Absorption by clothing, cushions, carpets, etc.

Sounds travel in liquids and solids as well as in air.

Musical Sounds

(a) Sounds and their pitch — the musical scales. Monochord and violin.

(b) Sounds and their loudness. Forced vibrations. Pianos and gramophones.

(c) Sounds and their quality.

Apply to orchestral instruments, organ pipes, talking films and the gramophone, and human voice.

Experiments may be done showing resonance in the human mouth. Show how sounds are produced in the new electrical musical instruments, e.g. the Hammond organ.

The Ear and Hearing

Link with physiology and hygiene. Compare the organ of Corti with the strings of a piano which are capable of selective vibration when a sound is made near the instrument. (The dampers must be lifted first by putting down the sustaining pedal.)

Electricity and Magnetism

If only from the utilitarian point of view, electricity demands the study of every boy, and in these days of 'all-electric' homes, of every girl too. Electric lights, wireless sets, telephones, the telegraph are so much a part of our lives that we should feel strange without them, but there are many applications of electricity which are just as important though less obvious, such as the purification of metals, the 'ignition' in petrol engines, electricity as a healing agent, etc.

Eighty years ago, and even in more recent times, there was a clear separation of the study into frictional or static electricity, magnetism, and voltaic or current electricity, and the first of these sometimes took up three-quarters of the whole time available. This division is not only undesirable but harmful, particularly in secondary school work where the connections between one branch of science and any other are developed as far as possible. Every year shows a further increase in the facilities offered by some new application of electricity, and this might prove a means of introducing the matter.

The topics to be considered will naturally depend on the type of course which can be taken, but the tendency to avoid the subject altogether in girls' schools is unfortunate as domestic work, cleaning, cooking by electrical apparatus are commonplaces and not novelties and luxuries. A course in domestic electricity need not be detailed. It can take as a starting point the electric cable as it comes into the house, and deal practically with switches, fuses and how to replace them, distribution boards, power consumed, meters and how to read them. Various domestic appliances and the principles involved will form the most important part of the work.

(1) Apparatus which depends on the heating effect of a current in resistance wire:

Electric lamps, fires, irons, immersion heaters, cookers, etc. Refrigerators employing the continuous gas circuit method which require a small source of heat.

(2) Apparatus which requires a small electric motor:

Vacuum cleaners, electric fans, hair driers, washing machines, bread-making apparatus, 'frothers', 'whisks', and stirrers, lemon

'squeezers', etc. etc., electric meters. Refrigerators requiring pumps.

The possible dangers of electrical apparatus which is beginning to wear may be mentioned. An earth wire should be fitted but this is not always done. Accidents are comparatively rare, but it is dangerous to touch faulty or worn apparatus (for example, a portable electric fire) when some part of the body is 'earthed', e.g. when taking a bath. Be careful to prevent electricity from earthing itself through your body, particularly on damp days or when the fingers are moist or when in contact with some 'earthed' object such as a water tap or gas stove. Dangers from fire, the desirability of periodical examination of circuits, and wiring problems may also be mentioned.

With the advent of the Grid, farms are now electrified and villages are sometimes in a better position electrically than some towns. Even a course in rural science which makes biology the subject of chief importance, cannot afford to neglect electricity.

The ordinary course in electricity may, in addition, contain some of the well-known problems which require simple mathematical calculations. With the more intelligent classes the idea of energy will be stressed and the relation of electricity to heat, mechanical and chemical energies will be dealt with. Not much time need be taken by a study of frictional electricity and its properties, but as it has such historical importance and as some of the experiments are striking, a lesson or two may not be out of place, and it should be shown to be of the same nature as 'current' electricity. The work of Volta, Davy, Faraday, and others on primary batteries is useful, as it leads up to the modern primary battery which is still indispensable in many ways. A course on magnetism may be taken historically and will link up the work with navigation on the one hand, and electromagnetism, which is the point of real importance in this connection, on the other. A whole lesson should be devoted to electromagnetism, stressing the work of Oersted and Faraday, for this leads to electromagnetic induction — a phenomenon which has been known for more than one hundred years and which is the basis of the action of all dynamos, motors, transformers, 'wireless', X-ray generators, etc. It must be stressed that primary batteries would be quite inadequate for

most of the heavier task which electricity has to do. Faraday's discovery showed how mechanical energy through magnetism could produce electric currents which, unlike those of the old frictional machines, represented a great amount of energy. As secondary batteries (accumulators) are frequently employed in motor cars, wireless sets and for emergencies in power stations they ought to be mentioned. It should be stressed that here is a reversible energy change. Electrical energy produces a chemical change, which on discharge of the cell will give back the electricity. Electricity has not been stored as such, and there is no analogy with the condenser. The various instruments for measuring electrical constants are worth consideration. Ohm's Law can be deduced by quite general arguments, and tested with home-made apparatus. Electrical instruments of all kinds may be quickly and cheaply constructed in the handicrafts shop and even fairly accurate instruments have become very much cheaper since they are so necessary on the dash-boards of motor cars and in wireless work. If the various effects of an electric current have been carefully considered many of the applications of electricity may form the basis of 'projects' which can be worked without the expenditure of too much time.

The more intelligent children, particularly boys, would do well to make a study of simple Alternating Current phenomena, as this type of current is becoming more general for commercial purposes, for it presents advantages from the points of view of generating and more particularly of transforming and distributing.¹ The nature of A.C. can readily be shown by means of a diagram but a practical demonstration is easily arranged. For a shilling or two a small hand-turned dynamo may be made from an old magneto magnet, a simple armature winding with connections to two insulated copper rings on one end of the shaft and a segmented commutator on the other. Flat spring brushes will pick up single phase A.C. at the rings, and D.C. which is of a highly fluctuating voltage, at the commutator. If the shaft is turned slowly, and the pairs of brushes are connected in turn to a simple galvanometer it will be seen that the needle oscillates from side to side with the

¹ Since this book first appeared vast strides have been made, particularly in America, in the transmission and transformation of D.C.

A.C., but keeps on the same side of zero with D.C. If the machine is turned more quickly in the second case a fairly steady position of the needle will be obtained. It can easily be deduced from what we have already learnt of electromagnetic induction that A.C. may be transformed to different voltages by static transformers (those without rotating parts). This leads at once to the problems raised in the distribution of electricity as in the Grid. In order to be able to carry a large amount of energy, voltages are made as high as possible (132,000 volts) and the currents (amperes) are reduced. This means that a thinner wire may be used and losses are reduced. Electrical energy (watts) is proportional to voltage \times current, and hence electrical energy lost in a conductor is seen to be 'voltage drop' along it \times current. By Ohm's Law this is proportional to C^2R , where C is the current and R the resistance of the wire. As heat losses increase with the square of the current it will be appreciated why it is a good plan to make this as small as possible by raising the voltage. The wisdom of this can easily be demonstrated by leading a low voltage alternating current through some yards of fairly high resistance wire to an electric bulb, which is only dimly lit. When the current is first transformed up in voltage and then at the other end of the resistance wires down in voltage the lamp is almost as bright as if there were no resistance wire. Here the few yards of resistance wire represent some miles of copper or aluminium conductors. Some interesting cinema films in 16 mm. gauge about alternating currents may be obtained from the Central Film Library.

An interesting demonstration of the various effects of an electric current is sometimes shown at the South Kensington Science Museum. An electric light bulb, resistance wire with thermometer, solenoid with nails hanging from it, a small motor, and an electrolytic cell are connected in series and energized by an appropriate direct current.

Applications of electricity, some of which are appropriate for inclusion in each type of science course:

Electricity in Manufacturing

(1) Electric welding.

(2) Making pure chemicals by electrolysis.

- (3) Induction furnaces.
- (4) Separating ores by electromagnets.
- (5) Making nitric acid from the nitrogen and oxygen of the air and water.
- (6) Electric motors for supplying power to all types of factories.
- (7) X-rays for revealing faults.
- (8) New applications of 'electronics'.

Electricity in the Home

The domestic apparatus has been mentioned previously. Other examples are:

- (1) Telephone, burglar alarm, electric door-bell.
- (2) Electric clock (for A.C. mains).
- (3) Wireless and television sets.

Electricity in Healing

X-ray for diagnosis (that is, locating injuries, diseases, or foreign bodies). Mass radiography of the chest.

X-rays for therapy (treating growths, skin diseases).

Radiant heat	} for rheumatics, chest
Short wireless waves	

affections, etc.

Finsen light, for skin diseases.

Artificial sunlight	} for producing vitamins,
Mercury vapour lamp	
Ultra-violet light	

treating rickets, etc.

Electrolysis, for destroying small growths.

'Ionization'.

There are many other applications, including the use of tiny electric lamps for exploratory purposes, electric currents for cautery (cutting by heat), the use of electricity for testing nerves and electro-massage for developing wasted muscles. There are even electrical methods for measuring psychological response and emotional feeling.

In Communications

Telephony and automatic telephone stations. Wireless telegraphy and telephony. Sending pictures by wire and 'wireless'. Teleprinters. Methods of securing secrecy.

On the Farm

Lighting out-houses by electricity. Electric stoves and incubators.

Electric power for working farm implements, separators, churns, pumps, milking and shearing machines.

General

It is interesting to take for example a modern super-cinema and think of the manifold applications of electricity which are necessary for its working.

Other examples are safety devices; timing apparatus; photo-electric instruments such as photographic exposure metres; church, cinema, and concert organs; dust extractors in flues and other miscellaneous pieces of apparatus are only rendered possible by the application of electricity.

Some subjects for Science Society Lectures and Demonstrations

High frequency phenomena.

High voltage testing.

How wireless valves are made.

Photo-electric cells and how they may be used.

Electric lighting and its history.

The Grid and what it does.

Careers in the electrical industry.

Electricity in gases.

Cathode Ray technique including television, radiolocation and the electron microscope.

Atom splitting.

Visits may be paid to generating stations, grid sub-stations, electrical-signalling gear, X-ray installations, automatic telephone exchanges, electroplating works, etc.

Class Reading

'Forces at Work'. Chapters i, ii, and iii.

Chemistry

In the past chemistry, particularly of the academic type, has occupied too great a place in the ordinary science scheme. Its importance is great, but in secondary school work when the early chemical processes have been mastered, chemistry will prove most useful in its relations to biology. In many ways it supplies a useful bridge between physical and biological studies. It is unnecessary

to say much about accurate quantitative work in chemistry here, for this is perhaps the one topic in school science which has never been neglected during the past thirty years and public examinations both theoretical and practical have done everything to encourage it. Accuracy and the proper handling of scientific measuring instruments are not to be despised, but the problem of applying the chemistry to life and to other scientific topics, is at least as important in grammar schools and more so in secondary and central schools. It must be kept in mind that the separation of chemistry into its branches, though perhaps necessary from the academic point of view, is undesirable in all but the most advanced of school courses. Organic chemistry is now the chemistry of the carbon compounds and the majority of vegetable and animal substances can be synthesized in the laboratory — even such compounds as Vitamin C.

Chemistry is susceptible to a very interesting historical treatment, and the work of Priestley, Lavoisier, Davy, Black, Dalton, and many others is worth recalling. It is good to begin with air and water, for these substances are absolute necessities to our existence and that of most living creatures. Sometimes a 'subject' method, though not to be recommended without qualification, proves very useful in this early work. Water can be treated from the physical, chemical, and biological aspects, which is a useful method in that it establishes early links between these points of view.

For instances, *Air* and *Water* may be treated in the following aspects:

Air

- (1) It is necessary for breathing.
- (2) Hot air rises. Balloons. Winds.
- (3) Oxygen and Nitrogen.
- (4) Burning.
- (5) Air and plants.
- (6) Vacuums and air pressure. Barometers.
- (7) Air dissolves in water. Breathing of fish.
- (8) Air may be liquefied.
- (9) Aeroplanes and birds.

Water

- (1) It is essential to plant and animal.
- (2) Many substances contain it.
- (3) Certain things dissolve in it.
- (4) It evaporates taking up heat. Ice, water, steam.
- (5) Rain, dew, humidity.
- (6) It is used as a standard of density.
- (7) It expands when heated. Convection currents and circulation.
- (8) It is a bad conductor of heat.
- (9) Light travels through it and is bent thereby.
- (10) It conducts sound.
- (11) Drinking and washing. Hard and soft water.
- (12) Water pressure.
- (13) It can be split up into gaseous constituents which will recombine to give water again.
- (14) Our water supply.

The effect of heat on various substances is an investigation which can easily be done practically by pairs of children, even where there is very little equipment. Even in heating the simplest substances there is scope for many observations, and the physical as well as the chemical changes should be noted. Combustion next takes our attention. Here care should be taken to lead children to see that combustion and incandescence, though sometimes simultaneous phenomena, are not necessarily connected. A historical treatment of combustion can be illustrated from the lives of the late eighteenth-century scientists and the work can be linked up with the child's growing conception of energy. Metal + oxygen = oxide + heat energy. The experiments either demonstrated by the teacher or through the personal work of the child will aim at showing:

- (1) That a substance will only burn in a supporter of combustion, usually oxygen.
- (2) That the products of combustion are heavier than the original substance which was burnt.
- (3) That incandescence results only when sufficient heat is produced to raise the temperature of solid particles above a certain level.
- (4) That there are processes in the body which are examples of

combustion. Just as much heat energy is obtained from an ounce of sugar burned in muscular action using up oxygen from the blood, as would be the case if the same amount of sugar were burnt in a special calorimeter in the laboratory and the heat measured; but in the first case the action is less vigorous. Sugar + oxygen = heat and muscular energy + carbon dioxide and water.

The study of acids and alkalis will grow out of an investigation of the products of combustion. We have sulphur dioxide (which when dissolved in water soon oxidizes to dilute sulphuric acid), carbon dioxide, and perhaps phosphoric acid; and on the other hand, the alkaline liquids which result by dissolving the oxides of metals in water. To these we may add such common substances as acetic and tartaric acids, baking soda and lime, and following Dr. Black's classical researches the broad differences between mild and caustic alkalis can readily be obtained. A study of the three chief commercial acids—sulphuric, nitric, and hydrochloric—can be made through their modes of manufacture and their applications to industry. The relations between acids, alkalis, salts, and the various action of acids on metals, and the idea of neutralization will form the subject matter of a lesson or two. In agricultural districts, the acidity or alkalinity of soils can be demonstrated by the beautiful colours given by adding B.D.H. Soil Indicator; and the necessary qualities of soil for crops of various kinds may be noted. The physiological applications of acids and alkalis are amongst the chief considerations of the bio-chemist, and often become very difficult. Nevertheless, in schools we may mention the various acids of the human body including the hydrochloric acid of the stomach and what it does, and its relation to healthy digestion.

Very often local industries will provide more topics in chemistry than can readily be dealt with and the type of course will determine how far these may be utilized.

Chemistry in Industry

Coal — Coal considered geologically; gas, tar, coke, ammonia.

(1) Carbon in various forms.

(2) The chief tar products including disinfectants, dyes, drugs.

- (3) Tar and its uses.
- (4) The burning of simple hydrocarbon gases.
- (5) Ammoniacal products and fertilizers.

Iron — Production of metals from oxides by reduction. Iron ore, coal, fluxes.

How iron is purified, various types of iron, steel and their qualities. Use of waste products from furnaces: (a) combustible gases; (b) road-making materials; (c) fertilizers.

Gypsum, Lime, Stone, Sand, Granite, Quartz, Alumina, and Metallic Ores

The quarrying of these substances will form an interesting link between geology and chemistry. If time permits something may be said of the conditions under which tin, china-clay, pumice, nitre, lead, copper, zinc, mercury, gold, silver, platinum, radium, and other useful substances are found. The starting point will be a short study of the substance and why its properties make it so useful, and this will be followed by an account of human endeavour to find the large natural supplies of the substance, and how to extract it from its impure or combined state as expeditiously as possible. Here the application of electricity on a large scale to chemistry may be mentioned; for example, the electrolytic production of pure copper for cables, etc., or the manufacture of aluminium for the wires of the 'Grid' in Scotland by using electric furnaces — for electricity can be generated cheaply where there are fast-running mountain rivers.

Glass — The combination of various types of sand or quartz with alkalis to make glasses. The different uses to which glass is put, and suitable types for each purpose.

Potteries — Pot and China ware. Glazes. The work of Wedgwood.

Petroleum — Where petroleum is found, how it is obtained from the wells, and the process of its purification. How hydrocarbon oils probably originated. The various petroleum products are separated by making use of their different boiling points. The combustion of petroleum in internal combustion engines. Various types of petrol; paraffin; vaseline; paraffin wax. Synthetic petrol-

eum in war and peace. The importance of fuel oils in world economy.

Plastics — See *Progress in Science* by the author.

Class Reading

'Things around us.' Chapters v and vi.

'Science and Life.' Chapter i.

'Forces at Work.' Chapters v, vi, and vii.

'Earth and Man.' Chapter iii.

All these industries may be illustrated by (1) Films; (2) Pictures; (3) Books; (4) Visits to museums with models of the type of works employed for the particular industry; (5) actual visits to the plant if the district permits.

Rural Chemistry

The Chemistry of the Soil

The chemical nature of soil, soil studies including the composition of various typical soils.

The growth of plants in soils from which certain constituents are missing. The carbon and nitrogen cycles.

The chemical action of bacteria.

Effect of manures and rotation of crops.

Types of fertilizer necessary in particular cases. Need for boron, copper, iron, etc., in the soil.

See Book IV, chapter iv, Andrade and Huxley, *Introduction to Science*.

The Chemistry of Milk

The constituents of milk. Cream, butter, cheese, and casein products. Protection of cattle.

Disinfectants, Germicides, Pest Destroyers

How they are made and how to apply them.

Scientific Feeding

Rehabilitation of farmland and cattle herds in Europe.

Although our course in chemistry is a means rather than an end there can be no objection in the A classes to a short discussion on molecules, atoms, or even electrons. The works of Dalton will make a convenient starting point. The connections with physics

will readily be seen; nor is it difficult to arrive at the idea of chemical formula, molecular weights, and simple calculations. Although the applications of science will form the greatest part of the teaching of this subject in secondary schools, nevertheless there will always be a number of intelligent children who will benefit by simple mathematical treatments of the science work and a certain amount of abstract thinking; and it is undeniable that if they can add this to their other scientific knowledge their intellectual grasp of the subject is strengthened considerably. The tendency to rely too much on mathematical treatment in chemistry is to be deplored; far better is it to seek qualitatively for the real happenings in a chemical reaction rather than to be satisfied with an ideal representation of the phenomena in terms of a simple equation, which in many cases is very far from actuality. Some distinction should be made between formulae representing such reactions as the action of acids on zinc where the yield of hydrogen is practically equal to its theoretical value, and formulae representing certain organic preparations where the mechanism of the reaction is often entirely overlooked and the yield is only a small fraction of the amount deduced from the formula.

Chemistry in the Home

Cooking

Carbohydrates. Sugars and starch. The nature of flour. Ferments and the action of bacteria. Yeast and enzyme action. Baking soda and carbon dioxide. Milk and its constituents. Vitamins and their preservation. Jams and Jellies. 'Pectin' and 'gelatine'.

Cleaning

Soaps and how they are made. Hard and soft water, washing soda. Ammonia, petrol, benzene, metal polishes. Disinfectants, and the correct types to employ in certain cases.

Paints and Varnishes

Drying oils, turpentine, colour washes and 'distempers'. Plastics, their nature and multiple uses.

Chemistry and Hygiene

The chemistry of breathing. The chemistry of digestion. The enzymes of saliva. Acids in the stomach. The splitting of fats. The

liver. The chemistry of bones. Calcium and phosphorus. Vitamins. The chemistry of blood. The kidneys and excretions of nitrogen. Endocrine glands and their secretions. Use of disinfectants. Action of well-known drugs. Antiseptic surgery, anaesthetics. D.D.T. and insect pests.

Some Topics for Science Societies

- (1) The chemistry of photography.
- (2) How margarine is made from crude oils.
- (3) Making tungsten, and other heavy metals.
- (4) Chemical experiments with liquid gases.
- (5) Explosives and explosions. Safety in mines.
- (6) Aniline and dyes which can be obtained therefrom.
- (7) Drugs found in plants.
- (8) Synthetic rubber and other synthetic organic substances.
- (9) The chemistry of the sun and stars, and what the spectro-scope tells us about them.
- (10) Vitamins.
- (11) Hormones and synthetic substances of similar nature.
- (12) Pasteur and his work with ferments.
- (13) The chemistry of oils, petrols, and gases used in internal combustion engines.
- (14) Pharmaceutical Chemistry.
- (15) The chemistry of rocks and ores.
- (16) The Alchemists.
- (17) The rayon and synthetic fabric industries.
- (18) Plastics, their story, manufacture and uses.
- (19) Radioactive substances.
- (20) The story of penicillin.
- (21) Sulphonamides and other synthetic drugs.
- (22) Uranium and the release of atomic energy.
- (23) Isotopes and 'Tracer Chemistry'.
- (24) Metals in the service of man.

CHAPTER VIII

ASTRONOMY, METEOROLOGY, GEOLOGY

Astronomy

PERHAPS no branch of Science excites the imagination like astronomy, which as a study is of the greatest antiquity and above all others gives man partial glimpses of the magnitudes of space and time and his own insignificance in the physical scheme of things. Astronomy has far-reaching connections with such studies as mathematics, light, chemistry, geography, and philosophy. Normally pursued for the joy of discovery, its beauty as a science, and the clues it gives to the mysteries of a systematic Universe will ever occupy the inquiring mind in its search for at least a partial idea of whence we came and where we are now. Nevertheless astronomy has very important utilitarian applications. Most observatories have gathered a considerable amount of purely cultural information but they are also occupied with problems of measuring time, standardizing chronometers, calculating tides, the problems of navigation, etc. Teachers of astronomy should make themselves familiar with the work of such observatories as Greenwich and Bidston in England. The work of the Mount Wilson and Palomar Observatories in America makes absorbing reading owing to the power of their telescopes and the consequent extent of their searches.

Astronomy has an interesting historical background. In the days before artificial lighting, when people slept on the roof-tops or out in the open, the minds of men were naturally directed towards stellar phenomena in very early times. Accounts of the stars figure largely in the scientific works of every generation. Astronomy and Astrology grew up together like many other forms of real and spurious studies. It was seen dimly at first and then more clearly that astronomical phenomena were systematic. The Chinese had a system, Ptolemy, and much later Copernicus, had others, and the progress of the study can be seen admirably through the works

of the great scientists Tycho Brahe, Kepler, Galileo, Newton, Herschel, Adams, etc.

(Sir Oliver Lodge's book, *Pioneers of Science*, gives an admirable outline of the preceding work.)

The work of Einstein is hardly comprehensible without a fair knowledge of mathematics, yet his theory of Relativity, coming as it did about two hundred and fifty years after Newton's theory of Universal Gravitation, is so often quoted, and represents such a considerable part of our present conception of the Universe, that a partial explanation of it on such lines as are given in Eddington's *Space, Time, and Gravitation* is almost a necessity to the senior and more intelligent children.

Astronomy should be linked up with the work in light which deals with shadows, reflection, refraction, colour, telescopes, cameras, and spectroscopes. Models of various types of telescopes are easily made from lenses, slightly concave mirrors, and cardboard tubes; and the work of Galileo, Newton, and Herschel can be recalled in this particular branch of astronomical work.

The Solar System

A study of the Solar System gives an opportunity of starting our work near home, comparatively speaking. The sun can be taken as a convenient central point, but it must be kept in mind that the Solar System is a very tiny part of the whole Universe and indeed there are stars, such as Betelgeuse, which if placed where the sun is, would extend to the orbit of Mars.

Few teachers will have at their disposal an old-fashioned orrery, nor is this necessary for very much simpler models will suffice. An electric bulb standing at the centre of a large bench may represent the sun and small wooden globes rotating on needles will serve for the planets. The correct proportional magnitudes will not be preserved, but these can easily be explained separately in terms of larger distances. Such models will demonstrate:

1. The meaning of a year for each planet, with special stress on the terrestrial year.
2. Day and night.
3. Satellites. The moon and the earth. The lunar month.
4. The sun in relation to the earth. The seasons. The tropics of

Cancer and Capricorn. The Arctic and Antarctic circles. The midnight sun, etc. Latitude and Longitude.

5. The apparent motion of sun, moon, and planets when observed from the earth. The phases of the moon. Lunar and solar eclipses.

6. The parallax of fixed stars outside the Solar System.

7. Comets.

The earth should be considered in relation to the other members of the solar system, consideration being given to (a) its probable evolutionary history; (b) its suitability for the various forms of life which it sustains; (c) its size and shape — related to various geographical considerations.

From the utilitarian point of view a treatment of time, tides, the shape and size of the earth, navigation, etc., will prove most useful.¹

Time

The rotating earth as a clock.

Various ways of measuring the mean day. Greenwich Mean Time. Sundials — how to make and use them. The year, leap years — the history of the calendar (mention may be made of the Julian and Gregorian calendars, and various times in history where adjustments in the calendar were necessary, the 'eleven days' riots', etc., and the importance of accurate ways of measuring standard time). Time in various places of the earth. Chronometers and other devices for measuring time. Their use on ships, particularly before the days of wireless. Wireless time signals, and the work of Greenwich Observatory. Electric clocks and how they are made — slave clocks. Electric clocks working off A.C. mains — the standardization of time on the National Grid. Teachers interested in Horology should read Mr. Hope-Jones' book, *Electric Clocks*, and R. W. Symonds' *A Book of English Clocks* (Penguin).

Tides

Tides should be considered from the points of view of navigation, fishing, bathing, etc., and hydro-electricity.

On the whole it is probably better to be content with a very general treatment of the effects of the sun and moon in various

¹ See *The Teaching of Arithmetic and Elementary Mathematics*, by the author.

positions, spring tides and neap tides, etc., and to limit the treatment of tides to this. The work of the Liverpool Observatory at Bidston has shown clearly that the explanation of particular tidal phenomena as given in most modern geography books is largely erroneous. Tides at any particular place and time are calculated by the superposition of a considerable number of harmonic (sine) curves, which can be done by a machine. This is largely beyond the scope of secondary school work, but teachers who are going to attempt this topic should know something of the work of the Bidston Observatory, which in its investigation on tides is unrivalled throughout the world.

Other topics which may be used for lectures to Science Societies if time permits

- (1) Meteorites or 'shooting stars'.
- (2) Comets, and how their identity is known from their movements.
- (3) The milky way (galaxy) and what it tells us about the Universe.
- (4) Some remarkable 'fixed' stars.
- (5) Nebulae, nebula-hypothesis and its difficulties.
- (6) The planets and how they were discovered.
- (7) How large telescopes are made.
- (8) Cosmic rays.
- (9) Aids to navigation.
- (10) Great circle flying.

Class Reading

'Things around us.' Chapter i.

Meteorology

Meteorology should be considered as a part of natural history and should be linked up with the work in the other branches of science. Apart from an interest in weather and climate from an academic standpoint, these are questions which affect everyone. Several times a day we receive wireless reports of weather forecasts which, apart from variations due to local conditions, are surprisingly accurate. Farmers, gardeners, anglers, sailors, airmen, builders, sportsmen, and others engaged in outdoor pursuits wel-

come some guidance as to the weather in the immediate future. It is certainly desirable to spend a few lessons in dealing with weather-forecasting, or in developing the subject from certain topics in the study of Heat and the properties of matter. Formerly the work was assigned to the geography course, but physical geography has been displaced to a large extent by human and economic considerations and the old physiography, which was quite useful in its way, has disappeared altogether. Nevertheless, the possibility of a close co-ordination of meteorology and geography should not be overlooked. In any case weather study should not be omitted, for it touches our lives and those of other living creatures at too many points. The study could develop on lines similar to the following:

Winds

Convection currents and how they are caused. The measurement of winds (anemometer and Pitot tube may be made in the handicraft room). Winds considered locally and with regard to the whole earth. Consideration of the possible truth of the old weather rhymes such as —

When the wind is in the east
'Tis fit for neither man nor beast.

Humidity and Temperature

'Good drying days.' 'Heavy atmospheres.'

Relation between temperature of the air and the moisture it will hold. Application to the formation of dew and hoar frost. Radiation from the earth. Clouds of various types and what we may learn from them. Rain, hail, and snow. Mists, sunsets, and sunrises. Evaporation and cooling.

A red sky at night is the sailors' delight.

A red sky in the morning is the sailors' warning.

Rain gauges of various types and the keeping of records.

Sun gauges and records of periods of sunshine.

Thermometers of various types.

Various ways of estimating humidity.

Air Pressure and Barometers

Barometers of various kinds including the self-recording aneroid type. Why the barometer goes down when the air is charged with

water vapour. How to keep a barograph. How wireless has helped to make comprehensive Meteorological Office reports. Isobar maps. Cyclones and Anti-cyclones. 'Depressions over Iceland.' How we may predict the weather in general terms by knowing the movements of anti-cyclones. Weather stations. (Theories of Polar fronts and the work of Bjerknes are not difficult to understand if a large globe is used and if there is a reasonable basis of physics.)

Younger children should keep weather calendars, and the small pictures representing climatic conditions which appear in the daily papers may be cut out and used in the school weather chart.

The work should always be related to the habits of birds, fishes, animals, and human beings throughout the seasons; and in different countries and climates to the seasonal growth of plants and trees.

Some further topics, if time permits, or for Science Societies

Exploring the atmosphere with long sound waves, short wireless waves, and pilot balloons.

Magnetic and electrical radiations from the sun and their possible terrestrial effects.

The tides and the weather.

Gales, typhoons, blizzards, 'water-spouts', cyclones.

Weather Reports for commercial and service aviation, how they are made and used.

Thunderstorms. Safeguards from damage by lightning.

Lightning and the production of useful substances from the air.

The war and the weather.

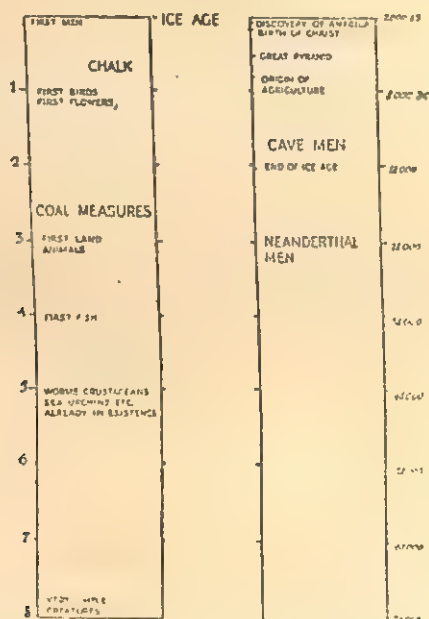
Class Reading

'Earth and Man.' Chapter i.

Geology

The history of the earth, of which the story of man's appearance is such a recent part, is of such importance and so fascinating a study that it cannot be overlooked in senior school work; but it is hardly possible that time will allow a separate treatment of it. Thus, Geology will be considered in its relation to other science subjects and it will include parallel references to the conditions of life on the earth at the various periods.

The early work on Nature Study cannot be considered complete unless it takes some account of the world of rocks, the earth, the action of water, wind and frost; and from this should grow in later school life an idea of the earth's crust and how it was formed. This work will proceed side by side with simple astronomical considerations of the earth as a spheroidal planet — a member of the solar system. This should be followed with a fuller account of the work of natural forces, the oceans and tides, rain, air, ice, glaciers, winds, contraction due to cooling, upheavals of volcanic origin, etc., and all should be closely related to geography. Unfortunately, in the past this correlation has been considered only from the physical point of view, but geography is a subject full of human values and such things as the origin of towns, villages, industries, and



'Some events in the history of the earth. On the left, a scale taking in most of the history of life. Each unit represents 100 million years. On the right, a scale taking in the last 80,000 years; this represents only the top ten-thousandth part of the scale on the left.

Further diagrams and evolution tables may be seen in Haldane and Huxley's *Animal Biology*, and these may be simplified by the teacher, drawn on large sheets of paper and small pictures added to illustrate life and conditions at each period.

various types of plant and animal life are directly traceable to geological conditions. Thus, the later evolution of the earth and the living matter which is, and has been, sustained by it will be considered side by side. In this connection it is useful to have a number of charts illustrating the phases of the earth's history. Many of these fail by being too detailed, and thus it is advisable not to compress too much on any single chart, and to vary the time scale from chart to chart. Even so, the period occupied by civilized man is represented by a tiny length of the time line. Man only appears on the last page of a large book about the history of the earth.

Children are always interested in fossils, for the idea of strange creatures once on the earth and now extinct captures the imagination; and a school museum should be kept with a number of labelled specimens including examples collected in the district if possible, in addition to those from other parts of the world. Geological maps of England and models of vertical sections of the strata in the district, across England, etc., should be made and preserved. Children should be encouraged to visit geological museums, and in particular the Natural History Museum at South Kensington, where due attention has been paid to geology and palaeontology and the exhibits are arranged in a manner which simplifies the task of grasping the question of the evolution of the earth and the living matter on it.

There is another side to geology quite apart from the necessary aspect of obtaining a larger knowledge of our history and that of everything around us.

Geology is of the greatest significance from the utilitarian point of view. The natural wealth which the earth yields up to man in minerals is of inestimable importance to our modern life and health. Coal, iron, limestone, stone, and clay for bricks, metallic ores, precious stones and metals, water for drinking and washing, petroleum and many other things are all obtained from the earth. A knowledge of geology does much to prevent the search for these invaluable substances from being haphazard. Many very valuable minerals are rare, and a study of rocks and their properties gives miners and prospectors some clue as to where to look for them. Radium is not only useful in the work of the surgeon who en-

deavours to cure cancer, but its behaviour in constantly disintegrating (or splitting up) may give us some clue to the age of the earth. All science teachers should deal with local geological conditions in their relations to industries, and visits should be paid to mines and quarries. The chemical processes for extracting metals and other useful substances from their ores will form a basis for some of the third year chemistry teaching, and if time permits simple physical, chemical, and other tests for minerals should be shown. Many important industries both at home and in the colonies are only possible by the exploitation of mineral wealth. The geologist is therefore a very useful member of the community. Geology may also be considered in relation to soil, agriculture, and healthy housing conditions, from the point of view of the engineer who wishes to bore tunnels through rocks or under rivers, or to make bridges, dams, roads, etc.; or the pioneer who wishes to develop a country, to make it fertile and to exploit natural potentialities.

Geology and life on the earth are dealt with in an adequate and readable manner in Chapter ii ('The History of the Earth') in *Earth and Man* by Andrade and Huxley, and the treatment presented leads naturally to the problems of the circulation of matter through life, the carbon, nitrogen, and other 'cycles' and to chapters on soil and agriculture. Professor Swinnerton's *Solving Earth's Mysteries* is an excellent book for class reading.

Topics for discussion and for Science Societies

- (1) The mining industry.
- (2) Rare minerals.
- (3) Sinking oil and other wells.
- (4) 'Prospecting.'
- (5) The contents of the earth's crust.

CHAPTER IX

BIOLOGY AND HYGIENE

BIOLOGY more than all the other branches of scientific knowledge deals with man's place in Nature, with the things immediately around us, with social questions, with phenomena which can be most readily observed, and with ourselves, our bodies, and how they work, and related to this our instincts and capabilities. Biology sums up and embraces to a large measure much of the knowledge acquired by more limited studies. The Hadow Committee repeatedly emphasized the importance of biological studies: 'In country schools the science syllabus both for boys and girls might be largely based on biological interests, the study of elementary physics and chemistry being subsidiary but arranged so as to supply the indispensable foundation for a course in elementary biology with special reference to its bearing on horticulture and biology.' 'We suggest that science courses for girls in Modern Schools and Senior classes should in their later stages frequently have a biological trend.' 'We regard it as especially important that instruction in elementary physiology and hygiene developing out of the lessons in elementary biology, should be given to all boys and girls in Modern Schools and Senior classes. Such instruction should be largely the practical outcome of a study of elementary biology treated not as a series of classifications but as a study of the development of form and function in suitable types of plant and animal life, leading up to a study of how the human body is built up and how it works. Such instruction in biology and elementary physiology if properly carried out might well provide the basis for a right attitude to many social problems.'

1. *Personal Hygiene*

How to keep the human organism fit, with subsidiary lessons on the importance of fresh air, sunlight, exercise, rest, and cleanliness.

2. *The Hygiene of the Home*

With special reference to light, ventilation, sanitation, the proper care of food and so forth.

3. *General Hygiene*

Which would include a brief account of the public health service, and the measures taken by public authorities to safeguard the health of the children.

The Hadow Committee further stressed the need for continuity with primary school work where the elements of nature study have been taken up to the age of eight and then discontinued until the secondary school is reached.

The past failure to teach biology was felt, of course, by young entrants to the medical, dental, agricultural, veterinary and many other professions, but its neglect had a more disastrous effect than this, for it presented in place of a broad scheme of science an extremely narrow aspect of it and one which would result in an inadequate or even perverse interpretation of the problems of life and the universe.

The study of natural history of which biology forms a large part sums up and embraces in a large measure the simpler work of the physical sciences. A considerable part of the work of the physiologist, for instance, is only applied physics and chemistry and for his researches he often applies very recent and complex developments of these subjects.

Biology integrates the elements of the other science subjects and shows their relations in a manner which gives an idea of the unity of science.

However, the physical sciences, whatever their limitations, will ever remain a reasonable basis for all the other branches of the subject and if that basis is weak the science as a whole will suffer.

Where biology has been taught in the past its chief weaknesses have been:

- (1) It was confined to botany, and then only as a subject for girls.
- (2) It had insufficient relationships to other branches of science and was built on weak foundations in the physical sciences.
- (3) It often stressed classification at the expense of a proper treatment of form and function.
- (4) It was not applied sufficiently to everyday problems, our bodies, food, etc., and it neglected the larger problems summed up as 'Natural History' which show the points of contact of the living and the inanimate worlds.

Until the present century the utilitarian aspect of biology has been overshadowed by the remarkable changes effected by the applications of physics and chemistry. Indeed, many pressing and important biological problems which are related to our happiness and health and not merely to the pursuit of commercial wealth have hardly been thought about yet. Many trades, the problems of agriculture, the preparation of foods, etc., were too often conducted in a haphazard or traditional manner.

We are at last waking up to the fact that the study of biology, even from the commercial point of view, is at least as important as that of electricity; indeed, from the cultural aspect it is greater, for it touches life at more points and has an enormous historical, geographical, and social significance.

Biology will naturally form the basis of hygiene and gardening, which are some of the most important subjects in the 'Senior' school syllabus. The care of the body machine, without which we can do nothing and which can never be replaced, is of such importance that many other subjects fade into insignificance beside it.

Instead of a detailed study of such living things as worm, cockroach, frog, rabbit, etc., which has become usual in the more academic courses of the grammar school, the secondary school teacher may prefer to make a more careful study of the flora and fauna of the environment of the school, the school garden, the local fields, woods, streams, rivers, and ponds. It is rarely necessary to do dissection of animals in secondary schools, and indeed it is not always desirable. Nevertheless, a treatment of typical plants and animals with regard to form and function is a necessity. A study of the earthworm, its life history and habits, is at once a useful and practical topic in gardening, and when coupled with an account of Darwin's work (a model of fine research with little that could be called apparatus and with the garden for a laboratory) the matter takes on a new cultural aspect. The life histories of the house-fly, bee, wasp, mosquito may be considered before that of the cockroach. The study of life histories is always yielding practical information of the greatest utility. On the one hand it gives us a clue to the control and destruction of pests and the eradication of diseases, and on the other it suggests means for the preservation and the propagation of useful creatures such as bees. The methods

of preventing the ravages of malaria, the 'Death Watch' and other wood beetles, the aphides and other pests which destroy fruit and flowers, and the parasites of animals and man, are all suggested by a knowledge of the life histories of creatures, which in the course of their complete existence undergo several changes.

A study of the frog and rabbit may be related to human physiology and hygiene. In each case we should deal with the equipment of the animal for its particular type of existence, its sense organs and their development, how it breathes and eats, how it moves, any notable changes which take place during its life, how it reproduces and any other striking qualities which it possesses, including its powers of adaptation to environment.

As we ascend to higher animals we see further differentiations taking place and highly specialized sense organs being developed. Whereas many of the lower animals are only sensitive to light, in the higher animals the reaction to light is not only localized but is developed to such a state that images are cast on a screen by a lens. A study of the eye and ear, related both to physics and to hygiene, is necessary, and if time permits other senses may be included. A simple treatment of the sense of touch, muscular movement, body control, the action of sensory and motor nerves will lead to a study of the central nervous system and the brain, which is one way of approaching work on psychology in later years.

The life histories of plants are equally important. The work can be related to gardening and a number of the standard experiments can be done with apparatus made from simple chemical glassware, or as in the case of klinostats and auxanometers from wood dowelling, simple Meccano parts, etc.

The following experiments may be done:

- (1) The germination and growth of various types of seeds —
 - (a) At different depths.
 - (b) At different temperatures.
 - (c) At different degrees of dampness of soil.
- (2) Experiments with corms and bulbs.
- (3) Growth in water containing various dissolved substances.
- (4) Light and carbon-dioxide are necessary for green plants.
- (5) Green plants in sunlight give off oxygen.

- (6) The evaporation of water from a plant—
 - (a) To show that a green leaf gives off moisture.
 - (b) To show the position of stomata on the surface of leaves.
 - (c) The effect of stopping evaporation from leaves.
- (7) The heat of germination.
- (8) The extraction of the green colouring matter of plants.

Careful observations of the successive stages of germination and growth should be made and represented in a number of large coloured drawings. (The above experiments with a number of others are set out for the use of pupils in the Practical Handbook to Book II of Andrade and Huxley, *Introduction to Science*.)

If time can be found, special studies with home-made apparatus may be made to show phototropism (movements with regard to light), geotropism (effect of gravity on plants), hydrotropism (effect of water near the plant).

Reproduction, Embryology, Heredity, Mendelism, etc.

The treatment of reproduction will arise naturally from the work on gardening and from the study of the life histories of plants and small animals. There is no need to isolate reproduction for separate study; it should be treated like nutrition, movement, and response to stimuli, as a normal function of all living matter, which for its successful survival both as an individual and as a race or species must be equipped in special ways.

The various modes of propagating plants by seeds, cuttings, grafts will arise in the work of gardening, and the essential similarities and differences in the reproduction of animals and plants will be noted. Microscope slides, showing that there is embryonic material at the tip of an onion stem, for instance, will show the difference between plant and animal growth, and will suggest differences in propagation.

A short anatomical study of various plants will show how they are adapted for 'crossing' and pollination by various natural and artificial methods; and seed dispersal should be discussed.

The work should always be applied to problems arising in horticulture and farming. The 'setting' of the fruit of 'self-sterile' and

'self-fertile' types of fruit trees makes an interesting study to the gardener who keeps an orchard.

The development of animals from the stage of the fertilized egg can be illustrated by a series of coloured plasticine or wax models showing cell division and the development of the embryo. (Modelling wax is exceedingly useful in teaching biology.) Permanent preparations in the form of microscope slides are valuable, and it may even be possible to examine the various stages of the development of the chick by opening eggs on successive days of incubation.

Many children will know that in selecting pet animals, race-horses, flowers, and vegetables it is important to know something about the parental history of the animal and plant, that is, the nature of the stock from which it came. Mendel's experiments (the value of which was not recognized for nearly half a century) on the crossing of peas make an admirable starting point, although it must be understood that there was some rather unsystematic knowledge or superstitious idea of cross-breeding before his time.¹ The basic facts of Mendelism are easy to grasp and simple diagrams will help to explain what happens when reproduction takes place. Diagrams showing chromosomes and genes within the cells will prove useful, and the work should aim at showing how an understanding of Mendel's principles enables man to control and improve many living things, how desirable characteristics may be encouraged and unwanted ones suppressed in the offspring by the careful choice of parents, during a number of generations. If the children have grasped the idea of the life of an individual commencing as a single fertilized cell which divides, subdivides, and gradually becomes complex and differentiated, the conception of heredity and the transmission of various characteristics are easy to follow, if suitable models or diagrams are used as illustrations.

Farmers, horticulturalists, and others who deal with plant and animal life have benefited by deliberate researches to improve living things by scientific breeding. As a result of Sir Rowland Biffen's work, wheat not only yields more grains to the ear, but is resistant to certain diseases which formerly destroyed the heavy cropping varieties. Peas have larger and more pods and the

¹ See Genesis, chap. xxx, v. 37-43.

height of the plant can be controlled, hens lay more eggs and have bigger breasts, cows give more milk, sheep more mutton and many times more wool, new types and colours of flowers, and new varieties of domestic animals are being produced through an understanding of the laws which apply to breeding.

In the case of human beings, although good surroundings, education, food, and clothing will do a great deal to make better men and women, the laws of heredity still hold (as applied not only to the body but to the mind); but as we do not use them we are constantly troubled by social problems which otherwise would not arise and there is a consequent loss in human efficiency and happiness. The teacher should stress that in all living things both Nature (heredity) and Nurture (food, environment) share the task of making the individual healthy and productive.

The above matters are admirably treated in Chapter vi (Development and the stream of life) and Chapter vii (The improvement of living things) in Book IV, 'Earth and Man' of the Andrade and Huxley *Introduction to Science*.

A study of the changes and improvements in living things wrought by breeding leads naturally to the problems of evolution. Theories of evolution did not begin with Darwin, but in 1859 he published his *Origin of Species* which should be read by all teachers of science, for, as a model of thorough and detailed observation, the marshalling of facts, and the drawing of conclusions, it will ever remain a monumental science classic. Darwin showed that environment and the rigors of external conditions were sufficient over periods of time to produce modifications in plant and animals, provided that it could be assumed that small differences or variations constantly occurred in the offspring. The characteristics which helped the plant or animal to adapt itself to survive under any new external conditions which it had to face, would tend to be transmitted and developed in future generations. Creatures which could not adapt themselves perished. New and complex forms appeared from changes in previous ones; but some, as the fossilized remains of extinct creatures show, found it impossible to adapt themselves quickly enough to keep pace with rapidly changing external conditions. It must be understood that although all biologists accept evolution they do not all go so far

as to think that all animal life resulted from successive stages of development of a single-celled creature. Evolution also takes place within the species as fossils show clearly. All scientists respect Darwin's great work but some believe that all living matter has an inner 'urge' which enables it to adapt itself to external conditions in some measure. Some psychologists have revitalized the theory of Lamarck (1744-1829) which says that the urge to adaptation comes from within, whereas Darwin maintained that it is forced upon the creature from without, and those creatures which cannot live in the new conditions must perish both as individuals and as a species.

The reasons why we believe evolution has happened and is happening may be summarized as follows:

(1) Some of the later fossils of mammals and other creatures give us clues to the nature of changes which took place.

(2) The forms and shapes of animals or plants of related species show likenesses which are most easily explained by the idea of evolution from common stocks.

(3) All animals develop from a single fertilized egg. In the case of animals the embryo in developing seems to sum up or recapitulate in a rapid manner the whole of the developmental history of the creature. (See figure 160, p. 318, of *Earth and Man*.) Many animals including man still have rudimentary organs — remnants of once useful parts of them. (Vestigial organs.)

(4) In his earlier book, *The Voyage of the Beagle*, Darwin gives an account of his observations of the geographical distribution of various species in the mainland of South America and the islands in the sea. The differences of environment had produced variations but there were evidences of common stocks. Large pictures will help to make the matter clear and a diagram of a 'tree' with branches coming from various parts of the stem and then further ramifying will prove invaluable to show the possible way in which various creatures, including man, have evolved. (See *Earth and Man*, chapters vii and viii.)

Work on classification will arise from the child's own observations during Nature-rambles in the district, but the teacher will supplement this by a series of lessons starting with the work of Linnaeus. The school science library should contain a number of

good floras, well illustrated in colour, together with books on birds, trees, insects, fishes and animals, which the pupils may use during their investigations. The children will realize that to name a thing is the first stage in getting to know something about it, and indeed if names are given in a systematic way, clues are yielded at once to the genus and species of particular plants and animals. In short, the seemingly clumsy and complex Greek (or Latin) names which are given to plants and animals really represent a simple 'card-index' system, which not only tell us something about the type of plant or animal, but show its connection with other members of the vegetable or animal kingdom.

Class Reading

'Science and Life'. Chapters iii to vii.

'Things around us'. Chapter vii.

'Earth and Man'. Chapters vi, vii, and viii.

Pond Life

A pond or sluggish stream in early summer will yield enough material to provide work for many lessons. Moreover, it is a study which can easily be related to other and higher forms of plant and animal life. Many of the specimens collected can be kept in captivity and will breed under suitable conditions; even mud dredgings and masses of decaying weeds will prove to contain many different specimens. The children will take an interest in collecting the material and a good pocket lens will be sufficient for a preliminary examination. Large-scale drawings of the plants and animals should be prepared and preserved, and it is well to relate Nature study to drawing wherever possible.

The following are some of the things which may be looked for and studied:

Algae, desmids, spirogyra, diatoms, duckweed (lemna), canadian waterweed (which has an interesting history), amoeba, paramecium (slipper animalcule), hydra, vorticella (bell animalcule). Experiments may be done on these rudimentary forms of life. The encysted amoeba (or other protozoon) may be studied by allowing its water to dry up. The hydra may be seen in the act of ingesting its food, for example, a water flea; and in each case

the arrangements for feeding, excretion, movement, reproduction can be noted and compared. Usually it is not difficult to provide conditions suitable for the reproduction of these creatures. If a flat round glass jar containing pond water, duckweed, and a little mud at the bottom is used, reproduction can be followed. A series of experiments on irritability will show that single-celled creatures, despite their comparative simplicity, seem to possess something related to intelligent and purposeful behaviour. For instance, the amoeba avoids objects unsuitable for food, it moves away from even the weakest acids, it assumes a spherical shape if touched by a needle, and it moves towards a light.

The single-celled amoeba may be compared with the unicellular green plant *chlamydomonas*, which is so small that a fairly good microscope is required to see it. This plant has remarkable powers of locomotion, and has a small red spot sensitive to light, but it is classified as a member of the vegetable kingdom because it has a cellulose wall and absorbs carbon-dioxide and salts in solution, and in the presence of light, photosynthesis, or the building up of chemical compounds (starch or sugar), takes place owing to the action of the chlorophyll of the plant.

Hydra (metazoa), a multi-cellular animal, and *spirogyra*, a many-celled plant, may be compared and contrasted, and in each case we note how the organism is equipped for performing what can be considered as the distinguishing marks of life: movement, irritability to various stimuli (light, heat, sound, acids), etc., feeding and excretion, and reproduction.¹

The hydra is particularly interesting in the variety of its methods of locomotion, its feeding, its powers of regeneration of lost parts, and its symbiosis (or 'mutual benefit' in living together) with a small green plant (*zoochlorella*). The hydra produces carbon-dioxide and other waste products which are absorbed, and by photosynthesis produce sugar in the plant, excess of which goes to feed the hydra. This may evoke comparison at once with the oxygen and carbon-dioxide exchanges between animals (including man) and green plants and trees, which are not symbiotic, of

¹ A short systematic treatment of these matters is to be found in Wyeth's *Elementary General Biology*.

course. A study of life at this simple stage will yield useful examples of both sexual and asexual methods of reproduction.

There is something of absorbing interest to children in the life histories of such tiny creatures and they will readily conduct their own investigations with little help from the teacher.

Ponds in summer also contain:

The univalvular snails (which are excellent scavengers in aquaria); bivalvular mussels; flat worms; cyclops (crustacean, a type of water flea). This creature of curious aspect is worth studying from many angles; the way in which the female carries its eggs and its means of locomotion are most interesting.

Water insects, including water boatman, water bug, water beetle. The latter may sometimes be seen attacking stickle-backs or even small frogs. Frogs and Newts.

Fish such as the stickle-back, which is more interesting during the breeding season. Dragon-flies and may-flies also spend the early and longest part of their life as aquatic insects. In the case of the dragon-fly there are two or three years of larva stage, and after this the insect grows wings and is called a nymph. Finally, the imago or fly emerges and leaves the water. In the case of the may-fly there is a sub-imago stage in addition, and the short life of the female fly, during which it lays its eggs, is proverbial.

Aquaria and other means of keeping living creatures in captivity

Aquaria are the most popular and effective means of keeping living creatures in science rooms. All teachers of biology will find an aquarium easy to run, very interesting and instructive.

The old-fashioned aquaria made of sheets of glass bounded by wooden frames are not recommended, for they are difficult to keep clean and water-tight, and dissolved substances from the wood and cement are liable to contaminate the water. Nothing better can be imagined for school-work than the large glass vessels used for accumulators. A suitable size is one which will present a front two feet high by eighteen inches wide, and perhaps a foot from back to front, though smaller sizes will serve. This vessel can be stood on a bench with its back to the wall in a dark corner of the laboratory. It should be enclosed in a neat wooden case with sides blackened internally, and a rectangular frame in the front.

The top of the jar can be covered with a wooden board sloping upwards towards the back, and fitting neatly over the wooden side pieces which will have sloping tops. Thus, all that is seen of the jar is a neatly-framed front panel of glass. Aquatic scenery may be painted on a card placed at the back and outside the jar, and this can be made to look very effective when seen through the water. The aquarium can be illuminated from above by a 60-watt bulb hidden from view in the sloping roof. Many fish tend to develop unpleasant fungi, which ultimately destroy them if they are exposed to too much bright daylight; and in addition, green algae grow on the glass sides and obscure the view. The bottom of the aquarium should have a fairly thick layer of clean coarse sand, and on this pieces of rock and fairly large shells can be arranged as shelters for the fish. Such plants as Canadian water weed, duckweed, water buttercup, starwort, and frogbit may be grown in the water; these are not only decorative but give off a certain amount of oxygen. This, however, cannot be relied upon, unless they are exposed to a certain amount of sunlight. The plants may not root in the sand, in which case they may be grown in flower pots placed at the bottom; or they may be rooted in soil at the bottom, which is then covered with a layer of clean sand.

When kept in captivity more fish die from suffocation than by starvation. Constant aeration of the water is essential. Aspirators working from a tap are popular; they tend to monopolize a sink and they waste water, but they can easily be made from a Winchester quart bottle, bent glass tubing including a T piece, and the whole apparatus, apart from any rubber tubing which is required for connections, can be made for a few pence. A more satisfactory way of providing oxygenation of the water, especially where there are a number of separate aquarium jars, is to use a tiny air pump driven by a small electric motor. It is not beyond the powers of most science teachers to construct a suitable machine; but the 'Aerofroth', obtainable from any naturalists' supply shop, is quite cheap, and is excellent where much aquarium work is done. Small water snails (*limnaea*) readily found in canals, are useful as scavengers and will help to keep the water clean. Water should be changed gradually and its temperature kept

from violent variation. Goldfish (carp) seem to be able to endure considerable abuse and their power of adaptation is remarkable, but the majority of fish are sensitive in one way or another. If salt water fish are to be kept the water should be brought in carboys from the sea; 'synthetic' sea water is not very satisfactory, but where it is used it should have a quantity of the real water added. Teachers who wish to study life in aquaria should take advantage of the experience gained at the Zoological Gardens, London, or at the Marine Biology Research Station at Plymouth, and they should read Mr. Boulenger's *Aquarium Book*. It is possible to make a balanced aquarium by choosing the fish, living plants and snails so that little aeration is required.

Formicaria are very easy to keep and are quite interesting, as the ants are always active; indeed, 'Ant-palaces' have become quite popular in American homes. A shallow box, enclosed with a piece of glass and filled with soil will suffice; but it is much better to have two vertical pieces of glass, separated by about four inches, and the narrow sides and bottom filled in with wooden strips. The work of the ants in burrowing and laying their eggs can be clearly seen. Of more practical value, particularly where there is a school garden, is to keep a beehive with glass sides. This can be fixed at the back of one of the side benches of the laboratory or other convenient room, with a small opening to the outside of the school. The work of the bees can be followed in comfort from the inside of the school, and in the garden in fine weather when they are collecting nectar and carrying pollen from flower to flower. This work is useful in connection with fertilization and the setting of fruits, the study of honey as a food and how it differs from the sweet liquid which the bees collect.

Mice, caterpillars, silk-worms, chrysalises of various kinds, examples of water life unsuitable for, or too small for, the aquarium may be kept in various improvised containers; but the many pests such as those which infect cut wood and trees are probably best examined *in situ*.

Special Apparatus for Biology

A considerable amount of apparatus for biological teaching may be made in the school workshops, and if this is done money may

be saved to buy a good microscope or micro-projector, which is also invaluable for work in physics and chemistry. A number of good pocket lenses are also a necessity. Aquaria, and the aerating apparatus, formicaria, vivaria, cages, beehives, small green-houses, Wardian cases, collecting boxes, etc., are made without much difficulty in the school workshop. An auxanometer can easily be made from a small wooden pulley, base-board, and dowelling, and it is possible by using an old clock and Meccano parts to make a serviceable klinostat. Such things as a potometer and other apparatus for showing transpiration in plants can readily be constructed from simple chemical glass-ware. Glass jam-jars, glass cells, flower-pots, and other cheap earthenware are never out of place in biological work. Petridishes, specimen tubes, and other simple glass apparatus are worth buying and are quite cheap. Dissecting dishes can be made by melting candle or paraffin wax into small roasting tins, so that the wax solidifies to a depth of about half an inch. The teacher should have at his disposal the common chemical reagents, a number of the standard stains, alcohol, Canada balsam, various media for bacteriological purposes, he should know their uses for particular tasks, and he should endeavour to make a good collection of microscope slides.

The purchase of a microtome is hardly justifiable for secondary and senior school work, but is it not beyond the skill of a science teacher with some experience of metal work to construct one, using a good razor and a carefully cut screw of small pitch.

An incubator for simple bacteriology can be made from a tin biscuit box, or sheet tin to which a hinged door should be fitted. The heat is supplied from a 15-watt electric bulb and a thermostatic device is necessary to keep the temperature constant. It is possible to devise one using the mercury-in-glass and electrical-contact principle, but it will probably prove more economical in the long run to buy a thermostatic cell for a few shillings and to fix to this a light metal lever, adjustable for various temperatures, which will open a circular vent in the top of the tin, permitting further circulation of air and consequently cooling the chamber. Alternatively an arrangement can be effected so that the current is switched off by the action of the expanding fluid in the cell until the temperature of the incubator falls. A pressure autoclave

for sterilization must be considered a luxury, but steam and air ovens useful for many things are easily made up in the workshops. Pictures of Linnaeus, Darwin, Wallace, Awebury, Metchnikoff, Pasteur, Lister, Mendel, and other great workers in the biological field should be included in the science portrait gallery, and charts made by the children illustrating the plant and animal kingdom, evolution, the geological periods and the nature of life on the earth at various epochs, drawings and paintings of individual plants and animals, the carbon and nitrogen cycles, the seasons of the year with appropriate plant and animal life, the effect of the contents of the soil on the growth of plants, etc., should be used for illustrative material.

Bacteriology

The applications of bacteriology to our daily life and the nature of common diseases will at once suggest methods of treatment of this work which should include:

(1) A consideration of bacteria as members of the plant kingdom.

(2) A historical treatment of the subject including the invention and development of the microscope and some mention of the work of Koch, Pasteur, Metchnikoff, Lister and Fleming.

(3) A practical study of common bacteria.

(a) The harmful germs contained in contaminated milk and water.

(b) Bacteria in the mouth, and on the body. 'Droplet' infection, which can easily be demonstrated with cultures of innocuous germs placed in the mouth.

(c) 'Spore-formers', why they are so resistant and how they are treated for purposes of sterilization.

The teacher should understand the methods of sterilizing instruments, petridishes, platinum wires, and the use of cotton wool plugs; the use of sterile media and the methods of incubation for the culture of bacteria; how the bacteria may be recognized and the number per cubic millimetre estimated. A collection of permanent microscope slides of common bacteria should be made. Tests should be made to show the resistance of spores to methods

of sterilization which would prove sufficient in the case of normal active bacteria.

Bacteria are a very low form of plant life and a special technique is needed for their study.

Hygiene and Public Health

A study of the specific bacteria of certain diseases will pave the way towards an understanding of the nature of the diseases, how epidemics arise, and how they may be prevented and cured. Bacteria are carried in the bodies of parasites, in refuse, in 'drop-lets', sputum, in milk, water, on clothes and books, some may float in the air, and some may form spores in which state they are resistant to considerable degrees of heat or cold. Bacteria may be killed by raising to boiling point, or in the case of spore-formers by boiling for a considerable period and reboiling. Light and various chemicals will destroy bacteria under certain conditions; oxidizing agents such as chlorine, hydrogen peroxide, and certain coal tar products such as phenol (carbolic acid) are particularly efficacious. The mechanism of the blood for destroying bacteria is more complex than is generally appreciated. The opsonins of the blood act as a 'relish' to stimulate the phagocytes (white blood corpuscles) to do their work. (Not all leucocytes have phagocytic action.) The action of germs in inoculating the blood against further attacks of the same or related diseases is more difficult to explain, and in any case it is still largely a matter of theory. The work of Jenner on vaccination (producing a very mild attack of 'cow-pox' in the patient) and the almost complete eradication of smallpox should be mentioned. Inoculation is the injection of serum, containing substances prepared in the blood fluids of other animals, which are antagonistic to a particular germ or germs, for example, those of lock-jaw (tetanus).

The story of the development of the sulphonamide drugs, such as those produced by May & Baker, the manufacturing chemists (M and B 693, etc.), can be related to a simple historical study of the use of chemicals in destroying or preventing the increase of harmful organisms in the human body. The treatment of infectious disease in this way is known as chemotherapy. The discovery of penicillin by Fleming in 1929 is an excellent example

of scientific observation and deduction made with very simple materials and leading to a discovery of first rate importance. The work of Florey and his colleagues at Oxford in the early years of the last war to isolate and purify the drug is a good example of the modern team work method of tackling a scientific problem.¹

The researches of Pasteur, who was the first to link a definite organism with the specific disease (anthrax) which it produced, prepared the ground for later work such as that of Lister. Germs, even those floating in the air, may cause sepsis and the formation of pus in an open wound. Lister studied the effects of various germicides and revolutionized surgical methods. To-day, we find that his work has resulted in aseptic surgery, where the aim is not to destroy bacteria which have already entered a wound, but to take all precautions to kill bacteria which might otherwise have reached it. Germs in milk are still a cause of tuberculosis. Lessons on milk should be given and the methods employed by dairymen to produce milk free from tuberculosis should be noted. Water and foods must also be free from harmful germs, and the means employed to obtain pure water and foods, and to test for harmful germs, should be known. Dental decay and many skin diseases are due to germs; but some diseases are apparently not produced by germs, or else the germs (or more properly viruses) are too small to be seen under a microscope, or to be caught by a filter. Other diseases, such as one type of dysentery, are produced by small amoeboid creatures — tiny members of the animal kingdom.

A study of bacteria and the human body should include:

- (1) A knowledge of common germicides and their value in appropriate circumstances. New drugs such as the sulphonamides and penicillin.
- (2) The value of light, heat (and cold) for destroying bacteria.
- (3) How the blood may be protected against bacteria. How infected persons should be treated.

The work can be linked up with history — for example, the Black Death, the Great Plague, the pestilence in the Roman Empire during the reign of Justinian, the difficulties of colonization, etc.; and with geography — for example, the work of making the Panama Canal which could proceed only when

¹ See *Progress in Science* (Blackwell), by the author.

malaria had been conquered, the problems of oriental diseases in the countries of the Empire. The effect of bacteria in ruining certain crops, etc.

On the other hand, the useful bacteria must be mentioned:

(1) Bacteria help to digest our food (work of Metchnikoff on sour milk, 'lactic' cheeses, etc.).

(2) Aerobic and anaerobic bacteria for treatment of sewage.

(3) Soil bacteria which convert nitrogen into nitrates and nitrites and are of the greatest possible importance to vegetable life.

(4) Certain forms of fermentation such as the making of vinegar, the flavouring of cheese, the curing of tobacco are caused by bacteria. (Alcoholic fermentation is due to the enzyme of yeast and not to bacteria.)

(5) Certain chemical processes on a large scale, such as the manufacture of acetone from starchy material.

Note. — Aerobic bacteria need oxygen, whereas anaerobic bacteria do not require it, but can sometimes live in the presence of it. Parasitic bacteria live on fluids from the tissues of animals and plants, but saprophytic bacteria produce enzymes or ferments which by chemical action yield foods for the bacteria from the substances on which they live.

Soils and their Study

Not only is this work of great practical utility and importance in view of the world food situation, but it can be linked up with geology, physics, chemistry, and many biological studies.

We may consider soils:

(1) *Physically and Chemically*

Their inorganic constituents — silicates, quartz, mica, iron, nitrates, lime, phosphates, etc.

The texture of the soil — air spaces, etc.

Organic constituents.

Humus (from decayed vegetable and animal matter). Manures.

(2) *Biologically*

Living contents of the soil and their uses: bacteria, fungi, protozoa, worms.

The relation of the soil to plants growing therein. Roots and root hairs.

Various crops, their particular needs and their effects on various types of soil.

(3) *Geologically, etc.*

How soils have been made by natural forces. Action of water, frost, wind, etc., on rocks. How man has made better soils; for example, alluvial soils by draining, soils in rocky barren ground as in the Island of Aran (see the film *Man of Aran*) by breaking up the ground mechanically and adding vegetable refuse, etc.

Sandy soils. Warm, light, and well drained.

Clay soils. Retain much water, have little or no aeration, are heavy to work and do not encourage good root development.

Loams. Clay, sand, and humus. Usually good fertile soils.

A rough examination to show the nature of a soil can be made by sieving a sample of the soil, and stirring it into about ten times its volume of distilled water. After standing for some hours the humus will rise as a scum to the top, the clay will remain as a slowly falling suspension in the water, and the sand will sink to the bottom. Humus may be extracted from soil by shaking it with strong ammonia, allowing it to stand for an hour or two, filtering, and carefully evaporating the filtrate.

Very good 16 mm. films on various aspects of soil study are available. Those dealing with root growth, root hairs, and micro-films showing the functions of the latter are particularly effective.

An excellent treatment of the subject is given in D. Hall's *The Soil*.

Biology and Gardening

(1) The soil, living creatures of the soil — useful and harmful. Bacteria of the soil. Manures. Digging, 'Tired' soils. Early and late soils.

(2) Germination, the growth of plants, feeding, breathing, irritability. Heliotropy, geotropy, hydrotropy. Reproduction, pollination, seed dispersal.

(3) How plants need water, capillarity, deep digging, 'mulching', hoeing, the correct way of watering plants. Watering plants in pots, watering bulbs in fibre.

Propagation of plants —

(a) Seeds. Cross pollination.

(b) Cuttings.

(c) Grafting fruit trees. Suitable stocks and scions for grafting. pruning (including root and summer pruning) of fruit trees. Fruit Pests, their life cycles and how to combat them. Mildew and fungi attacking plants.

(4) Suitable varieties of vegetables, flowers, shrubs, bushes, trees, etc., for various purposes and for various conditions. Cross breeding.

(5) Suitable work for each season. A gardening calendar.

In farming districts the work can be extended to a fuller treatment of agricultural problems, according to the requirements of the particular district. This will include some of the following topics —

(i) Rotation of crops.

(ii) Cereal crops, special conditions necessary, research which has been done to make disease-resistant and heavy-bearing wheat.

(iii) Special crops such as sugar-beet. How to increase the yield by 'crossing' and manures.

(iv) Bee-keeping. Life in the beehive. The extraction of honey. Diseases of bees. Care of bees in winter. Bees and flowers.

(v) Forestry. Trees and their woods. The uses of various woods. Conditions for ideal growth. Diseases of trees. Timber pests and their control (various wood beetles and their life cycles. Fungi, dry rot, etc.).

(vi) Dairy-farming. Various types of cows. Milk and its contents. Physiology of the cow. Bacteria and milk. Milk as a food. How germ-free milk is obtained. Cream and butter. Various types of cheeses. Other milk products.

(vii) Poultry and how they are bred. Diseases of poultry. Food for healthy birds. Eggs and incubators. The food value of the egg. Grading eggs.

(viii) Sheep-rearing. Wool and its products.

(ix) Other farm animals, their uses, their requirements for a healthy existence, how the breed is improved.

(x) Fruit trees and orchards. Grafting, 'budding', self-fertile and self-sterile types. Choice of stocks. Pruning (including root and summer pruning). Fruit pests; care of trees. Fertilization of flowers; suitable trees for various purposes.

The pamphlets issued by the Ministry of Agriculture and Fisheries, and the Natural History Museum, cover a wide range of biological research on practical and useful topics.

Hygiene

Hygiene should grow out of the other science work and the teacher should never lose an opportunity of finding applications of physics, chemistry, and biology to our bodily health. In some schools hygiene is taught in connection with the physical training course, which is a good plan, provided that this does not impose undue limitations on the course, and if its relation to the science work of the school is always kept in mind.

Topics in hygiene which arise from various scientific subjects:

(1) *Heat* — the temperature of the body — heat as energy. How heat travels. How it is conducted and conserved — convection currents, evaporation of water from the body. Health at various temperatures and degrees of humidity. The importance of the physical conditions of the air (temperature, humidity, and movement) to health. Ventilation. Clothing of various types. How to treat burns and scalds.

(2) *Light*. Light and health. Sunlight and growth. Vitamins. Artificial sunlight. Precautions in sun-bathing. Vita-glass. Light and germs. The eye as a camera. Testing eyes. Use of spectacles. Natural and artificial lighting of rooms. Light and heat treatment.

(3) *Sound*. Sounds and noises.

The ear and how it works. Effects of noise on health.

Electricity

How electricity enables us to keep our homes clean. How smoke may be abolished. Heating and lighting for health. Electricity

as a curative agent. X-rays. Electric shock and its treatment.

(Magnetism itself is not a healing agent as far as we can determine.)

Mechanics

How our bones and muscles form mechanical systems; work and energy of the human body.

Chemistry

The chemistry of foods.

How each type of food is digested.

The chemical substances of the human body. Chemical deficiencies and how they may be counter-balanced. The heat and body-building values of foods. Vitamins and what they do. Waste products and how they are eliminated. Ferments in the human body. The chemistry of the blood. Chemical messengers and the ductless glands. Poisons and how to counteract their effects. Soaps, hard and soft water. Some common drugs and their uses.

Biology

The development, structure, and chief functions of the body.

Breathing and circulation.

Digestion of food. The structure of the teeth and how to preserve them. Food values and relative costs. Cleanliness within and without. The kidneys and the skin. Exercise, rest, and sleep. Alcohol, its use and abuse. Various common diseases and how they are caused and may be prevented. Useful and harmful bacteria. Care of the eyes and ears.

Spread of disease by vermin. The relation of man to animals and plants.

The destruction of germs. Disinfectants.

There are other important aspects of hygiene which are often neglected; for example, the social applications of modern hygiene as a means of preventing wastage of life, time, and money, prolonging life and avoiding misery. Mental hygiene and psychology are difficult topics, but not to such an extent that the importance of the dual aspect of health — bodily and mental — cannot be mentioned at school. If the work of the final school year has been

done in a stimulating and helpful manner, with an account of the means at the disposal of the child for further study, the teacher can hope that the foundations of the knowledge he has laid and the enthusiasm and ideals of citizenship with which he has inspired the pupil, will serve as the basis of a series of later studies in social problems. Psychology, as a means of understanding the behaviour of man in relation to many social problems and the mental health and happiness of the individual, is one of the most popular studies in the Adult Education Movement.

Many cinema films in 16 mm. with sound track are available for hygiene teaching. The Kodak films are excellent, but many others may be borrowed without charge from the Dental Board, the Health and Cleanliness Council, the larger manufacturers of drugs, including the I.C.I. The films made for the Ministry of Health and the Central Council for Health Education are available from the Central Film Library, Imperial Institute, S.W.7.

A hygiene course is not complete without an account of the great workers who laboured to reduce the suffering of humanity.

The work of Jenner, Pasteur, Simpson, Lister, Ross, Fleming, and its bearing on the prevention and treatment of disease should be paralleled with such researches as Harvey's discovery of the circulation of the blood, and Hopkins's experiments on vitamins, which represent excellent examples of scientific reasoning in applied biology. The story of man's endeavours to combat disease may also be correlated with work in history; for example, leprosy and plague in the East, 'scurvy' on long sea voyages, plague, ague, small-pox in Europe, the ideals of health in the time of the Greeks and the work of Hippocrates, Parliamentary Acts for better sanitation and living conditions, the National Insurance Act of 1911; and geography, for example, healthy and unhealthy parts of the world. How to choose health and holiday resorts. Tropical diseases. Difficulties of acclimatization. White men and colonization. Malaria and the Panama Canal. Infection conveyed in transporting goods, etc.

Using the principles which we have already enunciated the teacher should select his material from the following suggestions:

Schemes of Work in Biology and Social Science for Use in Modern Secondary Schools

It is now possible to give the course which seeks to cover all the points mentioned in the previous chapters, and to fulfil the aims considered to be most worth while. A number of alternative courses are suggested to suit varying circumstances.

A Scheme of Work in Biology and Social Science

First Year — The Variety of Life. Elementary Hygiene.

Second and Third Years — The Machinery (or Processes) of Life. Growth and Development.

Fourth Year — The Inter-Relations of Life. Individual and Group Studies of some Biological Problems.

Fifth Year — Further Study of certain Basic Principles. Social Science.

First Year — The Variety of Life
Elementary Hygiene

The work usually done in the Nature Study Lessons of the Junior School is to be continued and enlarged upon. Several common animals will be discussed as an introduction to the study of

1. External structure.
2. Methods of food capture.
3. Methods of breathing.
4. Movement.
5. The homes of animals.
6. The habits of animals.

Plants and some of their activities will be studied in a similar manner. A simple study of soil in its relations to plants and gardening is included. A section on Hygiene deals in a simple way with such important points as cleanliness of person, clothes, school, and home, care of the teeth, and care of person.

Living things and non-living things. Characteristics of living things. Meaning of the term 'Biology'.

The common wasp. Life-story. Characteristics of insects. Some interesting solitary wasps.

Snails and slugs. Common snails and slugs of the garden. Pond snails.

Spiders. Structure of spiders. Life-story of the garden spider. Web-building. Kinds of spiders.

Kinds of plants. Flowering and flowerless plants. Parts of a flowering plant. Annuals, biennials, and perennials.

How seeds are scattered. Why seeds are scattered. Methods of scattering.

Toadstools and moulds. Flowerless plants. Fungi — general structure and kinds. Harm done by fungi. Useful fungi.

The soil. What soil contains. Kinds of soil. Value of sand, clay, and humus. Passage of water through soils.

The earthworm. How it lives. Value in the garden. Other kinds of worms.

The wild rabbit. How it lives. The hare.

Life in winter. Why winter is a hard time. How animals, plants, and human beings prepare for the winter.

Buds, twigs, and trees. Parts of a twig. Recognition of trees in winter and summer.

Seeds and how they germinate. Parts of a seed. What seeds require to germinate. How seeds germinate.

Life-story of a frog. Frog spawn, tadpoles, frogs. Other amphibians.

The three-spined stickleback. Appearance and life-story. Other kinds of sticklebacks. Use of colour in nature.

Water beetles. Appearance and life-story of the brown-margined water beetle. Other water beetles.

Life on the sea-shore. Plants and animals found on the sea-shore and sandhills.

Cabbage white butterfly. Life-story. Damage done by the caterpillars. Comparison with a moth. Other butterflies.

Birds and their ways. Bird structure — external. Bird habits. Migration.

Flowers and seeds. The buttercup flower. Willow catkin. Grass flower.

How animals feed and breathe. A summary of observations made throughout the year on the methods of feeding and breathing used by the animals discussed.

Hygiene

Necessity for cleanliness. Washing and bathing. Cleaning the teeth. Clean clothes. Cleanliness in the home and school. Getting out into the sun and fresh air. Getting sufficient sleep. Going to the lavatory. Spitting, sneezing, and coughing. Treatment of cuts and burns. Dangers from gas, fire, and electricity. Safety first.

*Second and Third Years — The Machinery of Life
Growth and Development*

In these years the life processes going on in human beings, animals and plants will be studied. As far as possible the main idea will be to study structure, movement, digestion, respiration, etc., in man, and follow this with a comparative study of the same processes in some common or well-known animals.

The work on plants centres upon the basic facts of plant nutrition, leading up to the study of the importance of food-making in plants to us and to animals, and to the interdependence of plants and animals.

Work will also be done on the important problems of growth and development. Reproduction in plants, and animals, and human beings being dealt with in a simple manner.

Characteristics of living things. Division of labour. Protoplasm and cells.

The framework of our body. Necessity for a skeleton. Parts of the skeleton. Importance of sitting and standing correctly.

The framework of animals. Vertebrates and invertebrates. Comparison of framework of vertebrates with that of man. Bone structure and rickets — importance of correct feeding, sunlight, and fresh air. Housing conditions and rickets.

Muscles and movement. All movement produced by muscles. Structure of muscle and how it works. Kinds of muscle. Value of exercise. Muscle in vertebrates and invertebrates.

How animals move. Moving on land — on 'all fours', on two legs, crawling. Moving in water — sculling and rowing, other methods. Moving in air — what a flying animal must be. Flying and gliding. Successful flying animals.

Why the body needs food. Kinds of food required. Food required for energy, heat, growth, health. Kinds of food — energy

producers, body builders, health givers. Importance of balanced meals. Food buying and cooking. Planning out meals.

What happens to the food we eat. The digestive system and digestion. Enzymes and hormones. Getting rid of solid waste from the large intestine.

How animals digest their food. Similarity to man. Flesh-eaters, plant eaters, flesh and plant-eaters. Food getting. The sun and the food supply. Carnivorous plants.

How man obtains oxygen. Why man and animals must breathe — energy. Composition of the air — useful and harmful constituents. How man breathes. What happens to the oxygen. Abnormal breathing — oxygen want, breathing at high pressures.

How animals obtain oxygen. 'Free' air breathers, dissolved air breathers, 'free' and dissolved air breathers. Knowledge of breathing in animals applied to the destruction of pests.

Transport of food and oxygen. The blood — composition and work. How the blood circulates. The lymph system. Blood systems of animals.

Getting rid of waste. How waste is formed in the body and how it is excreted. How animals get rid of waste. Disposal of waste — sewerage, guano, etc.

Keeping the body warm. How heat is produced in the body. How heat is distributed, lost, and regulated. Cold and warm-blooded animals.

What plants obtain from the soil and air. What a plant contains. Sources of food supply — air and soil. Use of manures. How a plant obtains food from the soil. Transpiration.

Food-making in the green leaf. What is required for food-making. Action of sunlight. Transport of plant foods, and storage of foods. Other ways of food-getting.

Movement in plants. Types of movement in plants. Movement not muscular. Flow of sap. Movement in lower forms of plant life.

The nervous system. Parts of the nervous system and their work. Stimuli and sensations.

Getting information through the skin. Kinds of nerve-endings in the skin. Pain as a warning signal. Deadening pain — anaesthetics. Internal sense-organs. Touch, pain, and heat sensations in animals.

Information through our senses of smell and taste. How we smell things. The sense of smell in animals. How we taste things. Kinds of tastes. Taste in animals.

News through our eyes. Protection of the eyes. Structure of the eye. How we see things. Correction of eye faults. Sight in animals — development from eye-spot to highly sensitive eye-ball.

News through the ears. Ear structure and how we hear. 'Ears' in vertebrates and invertebrates. The ear as an organ of balance. How animals communicate with one another.

Thinking and doing — intelligence. Work of the great brain — (a) receiving and sending messages, (b) remembering, associating, reasoning, and thinking. Behaving intelligently — experimenting, inventing, improving, learning from experience; education. Forming habits. Reflexes and conditioned reflexes. The sympathetic system of nerves. Hormones. Brain work and sleep.

Do animals think things out? — Instinct. Comparison of animals' brains with ours. Examples of animal behaviour. Are some animals intelligent? Instinctive behaviour. Reasons for man's supremacy over animals.

Do plants think? Are they sensitive? Have plants a nervous system? Tropisms.

Growth and Development

Keeping the race of plants and animals going. Reproduction by fission — amoeba, bacteria, budding in the hydra. Reproduction in the hydra — ova and sperms. Development of the fertilized ova. Reproduction in plants — pollination and fertilization. Reproduction in fish — wastage of life. Reproduction in frogs — separate sexes. Reproduction in higher animals — bird, rabbit. Reproduction in human beings.

Development and growth in man and animals. First years of baby's life — infant mortality, and child welfare centres and clinics. Development from baby to adult. Development in animals — metamorphosis. Ductless glands and growth.

Variation and heredity. New plants and animals. Variations due to (a) environment, (b) heredity. Dominant and recessive characters. Inherited characteristics — chromosomes and genes.

The work of Mendel. Practical applications in the improvement of crops and cattle.

Fourth Year — The Inter-Relations of Life

Individual and Group Studies of some Biological Problems

It should now be possible to deal with the relations and associations of animals and plants with each other and with the lives of human beings. The effects of these associations will be considered under such headings as 'Partners and Parasites', 'Health and Disease', and 'Health and the Community'.

This year should also offer an opportunity for studying biological problems by individuals and groups. There are plenty of biological topics and problems worthy of study; some suitable mainly for town children, some for country children, while some will be suitable for both town and country children. Many of the subjects may deal with the biology of the district. This is an important side of such study, for with these older children the biology should be closely related to their everyday life. The following short list of topics will give some idea of the work which can be done:

The food supply of our city, town, or village.

Disposal of waste in our city, town, or village.

Health services of our town, city, or village.

Seasonal changes and the effects on living things.

Insects in relation to man.

Animal pests in the home.

The healthy home.

Biology of the farm.

Biology of the desert.

Biology of an African village.

Rabbits and rabbit keeping.

Soils of the district.

Life in some pond of the district.

Population of the soil.

For some of these topics it is clear that some outside help will be necessary. It has been my experience that sanitary and health authorities, housing directors, museums, and farmers are only too

glad to help in arranging visits or in providing photographs, graphs, or other material.

The method of carrying out this work is given in detail in the next chapter.

The Inter-Relations of Life

The plant and animal kingdoms. Uses of classification. The animal kingdom — the various groups. The plant kingdom — flowering and flowerless plants.

The sun, plants, and animals. Interdependence of plants and animals — food chains. Necessity for sunlight in food-making by plants. Sunlight and life — no sun, no life. Effect of (a) night and day; (b) the seasons. Other uses of plants to man and animals.

How plants and animals defend themselves. How plants defend themselves against other plants, animals, and the weather. How animals defend themselves against other animals, changes in temperature, food and water shortage. How man protects himself against man, animals, conditions, food and water shortage.

Parasites and partners. Plant parasites — fungi, moulds, bacteria, mistletoe, etc. Animal parasites — ichneumon fly, warble fly, bugs, lice, fleas, etc. Work of biologists — using parasites to destroy pests. Partners — symbiosis — hermit crab and sea anemone, hydra, lichens, etc. Man as partners and as parasites in a community.

Bacteria and their work. Types of bacteria. Experiments on bacteria. Useful and harmful bacteria. Bacteria in the soil. Partial sterilization of the soil.

Health and disease. Causes of disease. How disease bacteria are spread. The fight against disease — body's own defences. How man helps — vaccination, serum treatment, immunization, antiseptics and disinfectants, chemo-therapy. The folly of patent medicines. Animal and plant diseases.

Health and the community. The Ministry of Health and its work. Public Health Acts. Local councils and health bodies. The Medical Officer of Health. Notification of infectious diseases, isolation and fumigation. Inspection of food. Slum clearance and town-planning. Workshop and Factory Acts. National Health

Insurance. Child welfare movement — clinics and health centres, nurseries and nursery schools. School medical services. Open-air schools.

Fifth Year — Further Study of Certain Basic Principles
Social Science

The heading 'Social Science' alone might have been sufficient to indicate the work to be done in this fifth year, since the basic biological principles to be studied have their applications largely in the realms of social science. But it is with a definite object in mind that we have used the two headings, 'Further Study of Certain Basic Biological Principles', and 'Social Science'.

The children should by now, if the course set out has been followed, have a fairly good elementary grounding in the general principles of biology. But there are certain basic principles which may have been omitted in the earlier years of the course as being too difficult to be taken. Particularly does this apply to many of the vastly important problems of nutrition, respiration, evolution, heredity, and soil science. The knowledge of digestion and nutrition, respiration, and heredity in the possession of the children can now be further extended and some of the more difficult, but vitally important, aspects considered at this stage with greater profit. For example, we may in the earlier study of food and nutrition have found it impossible to do any work on the relative values of various types of proteins; on the calculation of food values or on the effects of cooking and storing on foods; we may when discussing 'Why man requires oxygen', have found it beyond children in the second year or third year to understand profitably any calculations of oxygen requirements of man, or respiration under abnormal circumstances. The work of the ductless glands and hormones, already treated in a somewhat very elementary manner, could also be considered a little more thoroughly. Much valuable work can also be done by these older pupils in further extended studies of the soil, soil management, and its relation to food production, while some work on forestry might be included. These topics and their applications to human welfare could now be taken with the older and more developed children of the fifth year.

In this year, too, some work must be done on evolution, with its immensely important problems and bearings on human society.

Now we come to that part of the work to which we have given the name 'Social Science'. In this we visualize a new outlook on the teaching of biology and other school subjects, and a new technique in teaching which will require some explanation.

Three factors need to be taken into account in considering the work for these older children of 14 to 16 years.

They will have had some experience in individual work, and in looking up data and references. They will have some knowledge of biological principles, and the application of these principles. Furthermore, these children will have reached the stage when they begin to take notice of the world about them, and will now be showing an increasing interest in the practical problems of life and work. Life is beginning to have a meaning for them, and they are coming into closer contact with its difficulties.

The second factor to bear in mind is the general isolation of school work from the daily life of the people. One sometimes was inclined to wonder what one learned in school had to do with the daily routine of adult life. Certain steps have, of course, been taken to remedy this state of affairs, and to relate the work of the school more closely to the daily work and leisure of the people by giving more attention to the ways in which mathematics, science, geography, and the other 'subjects' of the curriculum have their applications in life. Increasing interest in visits to factories, council meetings, health services, etc., also is doing much in correcting this state of affairs. But as yet this has not received general recognition in schools, but has been left to the really keen teachers who are out to explore new avenues for improving their teaching to bring it into closer touch with life.

This brings us to the third point which must be considered before we can outline what can be done for these older children. Almost universally we teach 'subjects'. We divide the curriculum into the more or less water-tight compartments of sciences, geography, mathematics, English, scripture, etc. We may seek to salve our consciences by attempting some correlation, but that is about all.

*A Four-Year General Science Scheme¹**First Year**Autumn Term*

The things about us. Living and non-living things. How do they differ?

Some living things about us. The common wasp. Snails and slugs. Spiders. Kinds of plants. How seeds are scattered. Toadstools and moulds.

Non-living things. Solids, liquids, and gases. How do they differ? What do we mean by melting and boiling? In what ways some materials are useful — flexible, malleable, rigid, etc.

Why do things fall? Why do we require a skeleton? What do we mean by 'force'? What makes things fall? Why we need a framework of bone. Mass, weight, and position.

Making the bus safe. Safety and the centre of gravity. Why do we stand with feet apart to stand firmly?

Measuring the pull of the earth. Can we measure it? What Hooke discovered. The spring balance — using the elasticity of a spring.

Are other things elastic? What we mean by elasticity. How we make use of the elasticity of stretching. Elasticity of bending — is steel more elastic than elastic, wood, or iron? Elasticity of twisting — making use of it. How our muscles work — keeping upright.

Why does a ball bounce? Elasticity of air. Making use of the elasticity of air.

How we weigh things. Primitive man and the invention of simple machines. Using a crowbar — the lever. The shop scales as a lever. Ways in which we use levers. Our arm as a lever. How we and animals move.

Our water supply. What happens to the rain when the street dries? Evaporation. Making use of evaporation. How rain is caused. What happens as the rain passes through the soil? Solution and crystallization. How plants get the minerals they need. Why we use manures and fertilizers. Why do some waters give a good lather and some do not? How we can remove stains and grease marks. How springs and rivers are formed. Storing water — where is the best place to build a reservoir? Work of the water engineer. Construction of the dam — water pressure. How is the

¹ Due to Mr. Frank Tyrer.

water made fit for use? Water not fit for drinking. Taking the water to town. Water in the home — tanks, pipes, taps, traps. Why has the water in the public baths a funny taste?

The earthworm. We examine the earthworm. Its life-story.

The wild rabbit. Its ways of living and its life-story.

Life in winter. How man, animals, and plants prepare for the winter.

Spring Term

From where do we get heat? The sun, friction, electricity; we produce heat, etc.

Why is there a gap between railway lines? What happens to a metal when heated? What an engineer has to remember. Making use of expansion, and allowing for it.

Do liquids expand when heated? Do they expand at the same rate? How does the thermometer work? Kinds of thermometers. What causes the pipes to burst in winter?

Do gases expand when heated? The housewife and the hot-water bottle. What happens in a balloon and a gasometer on hot and cold days?

Effect of increasing warmth on living things in spring. Buds, twigs, and trees. Seeds and how they germinate. Tadpoles and frogs. Water beetles.

Summer Term

Life on the sea-shore or in the pond. The cabbage white butterfly. Its life-story. We examine the butterfly. Making use of colour in nature.

The three-spined stickleback. What he is like. His life-story. Birds and their ways.

Flowers and seeds. The parts of a flower. How the wind and insects help in the formation of seeds.

How animals feed and breathe — a summary of the observations made throughout the year on the methods of feeding and breathing used by the animals discussed.

Hygiene — to be taken throughout the year. Necessity for cleanliness. Washing and bathing. Cleaning the teeth. Clean clothes. Cleanliness in the home and school. Getting out into the sun and fresh air. Getting sufficient sleep. Going to the lavatory.

Spitting, sneezing, and coughing. Treatment of cuts and burns. Dangers from gas, fire, and electricity. Safety first.

Second Year

Which is heavier — 1 lb. of lead or 1 lb. of feathers? Heavy and light things. What we mean by density. Which is heavier — water or alcohol? How do we test the amount of water in milk?

Why does an iron ship float? Revise what has been done on liquid pressure. Effect of water pressure on a diver. Why does a cork float and iron sink? Archimedes and his discovery. Why a ship floats. What is the Plimsoll line? Submarines and floating docks. Balloons and airships.

How a cycle pump works. Some simple experiments and tricks to show air pressure. Why we can use a straw to drink milk. The syringe and the village pump. The cycle pump. How does a barometer work? How can an airman tell his altitude? How the vacuum cleaner and the vacuum brake work. Making use of compressed air — the diver, pneumatic drills, carrier tubes in shops.

What is air? How do we know there is air about us? What is this air? Is there any difference between the air of the town and the air of the country or seaside? Can we get oxygen by itself? — oxygen and its properties. Can we get nitrogen and carbon dioxide by themselves? — preparation and properties. What happens when a thing burns? Oxidation and oxides. What happens when iron rusts? Can we get the oxygen back from an oxide?

What is water? Of what is water composed? — mixtures, compounds, and elements. How water was decomposed. Making hydrogen gas — properties. Solutions and crystals. Distillation of water.

What is an acid? What happens when some oxides (non-metallic) dissolve in water? Vinegar and lemons contain acids. Other acids. Why do we dab soda on a nettle sting? Why do sour apples make us ill? What an alkali is. What happens when we mix an alkali with an acid — salts. What soap is and how it is made. Why do we use hot water and soap for cleaning?

Why do we require food? (a) Energy needed for all our movements. How do we get this energy? — refer to work on oxidation of carbon. Foods contain carbon. Oxidation of this provides

energy. (b) Is this the only reason we require food? — growth and protection.

What are the best kinds of food for energy-production, growth, and protection? Balancing our meals. What happens to the food we eat? Digestion of the food we eat. Getting rid of waste. What happens to the digested food?

Animals and their food. How they digest it. How they capture their food.

Getting energy from the food. Why man and animals must breathe. What man breathes — smoky towns. How man breathes. What happens to the air breathed in? How breathing is controlled. How animals breathe. Making use of our knowledge of animal respiration.

Transport of food and oxygen. The blood — work done by various constituents. The blood of animals. How the blood travels round the body. Lymph and lymph vessels. The blood system in animals.

Getting rid of waste. The kidneys and liver. The skin. How animals get rid of waste. Disposal and use of waste.

Where do we get the gas from? Why is it called coal gas? What is coal? What happens when we burn coal? What happens when coal is heated out of contact with air? Making coal gas. Supplying coal gas to the town. How the Bunsen burner works. Gas stoves and gas fires. Reading the gas meter. The wonderful things made from coal.

Why the soldering iron has a wooden handle. How heat travels along a poker heated at one end. Does it travel through all materials at the same speed? Why we use cork mats in the bath-room — good and bad conductors. Use in daily life. Why has a boiler to be cleaned out at intervals? How the miner's lamp works. Are liquids good conductors? Is air a good conductor? Making use of this knowledge.

Keeping the body warm. How heat is produced in the body. How the temperature of the body is controlled. Clothes to keep us warm, and clothes to keep us cool. Stuffy rooms and ventilation. Heat control in animals.

How the bath water becomes hot. How does the water in a pan become hot all over when we know it is a bad conductor?

Convection currents in liquids. Making use of this knowledge. The household hot water system. The earth's warm-water system.

How draughts and winds are caused. The hot air balloon — why does it rise? Experiments to show hot air rises and cold air falls. What is a wind? Draughts in the house. Why do we use a blower when the fire is low? Using hot air to warm buildings.

How does the sun's heat reach us — by conduction? By convection? Then how? Experiments in front of the fire at home. Radiant heat. Reflecting and absorbing radiant heat — Archimedes' heat machines. The burning glass. Making use of radiant heat. Do radiators really heat a room by radiation? Heat and the soil. Why are some kitchen utensils black and some polished? How does a thermos flask work?

Change of state. Melting and boiling. Making use of melting and boiling.

Why can't we see in the dark? How and why we see things. Light and shadow. The sun — our source of light. Do all stars and planets give out light like the sun? What is an eclipse? How does a mirror work?

How do the piano and the gramophone work? How sounds are made. How do we hear sounds? How the piano works. Making and hearing a gramophone record. High and low sounds. Soft and loud sounds. How are echoes formed? What is the difference between a noise and a musical note?

The changing face of the earth. Was there always sand and soil on the earth? Why is the earth's surface changing? Kinds of rock.

The weather man. What is his job? How does he make weather forecasts? The witch doctor as a weather man.

Third Year

How a compass works. What is a magnet? Why does it attract iron? The magnetic needle — the earth as a magnet. The lodestone and mariner's compass. The compass on a hike. Attraction and repulsion of poles. What is a magnetic field?

How a flash lamp works. Who made the first battery and what was it like? — Galvani and Volta. The simple cell — how it

works, its faults. Other kinds of cells. What a flash-lamp battery is like. How it works. Other kinds of dry batteries. Wireless batteries. The accumulator — why has it to be charged?

How do we measure electricity? The electrical units — volt, ampere, ohm, and their relationship. Ohm's law. What is meant by 'series' and 'parallel'? What do we mean by a circuit? Why do we use copper wire in electrical work? Why are the wires usually covered? The resistance box.

How does the electric fire work? Heat production by an electric current. Making use of resistance — electric iron, radiator, etc.

How do we get electric light? How an electric current can be made to produce light. What were the first electric lamps like — Edison's work. The modern electric lamp. The arc and other forms of lamps. The household circuit — arrangement, fuse box, etc. How to read the meter — cost of household supply, measurement of consumption in watts and B. of T. units. The all-electric house — points, etc.

How does an electric bell work? Making a magnet by electricity. How a morse tapper works. The electric telegraph. How an electric bell works. How an electric motor works. How an electric tram or train works. How a telephone works.

What is meant by electro-plating? Chemical effect of a current. Meaning of electrolysis. Making use of electrolysis — electro-plating, chemical manufacture.

How does a camera work? Bending rays of light. Lenses. The box camera. How a camera works. The sensitive film. Why we use a lens in a camera. How a lantern and cinema projector work. How a searchlight works. The telescope and microscope.

What is a rainbow? Prisms, the raindrop as a prism. The solar spectrum. Why things are coloured. Colour in the home.

The nervous system. Thinking and doing. The nervous system. Getting information through the skin. Information through our senses of smell and taste. News through the eyes. News through the ears. Thinking and doing. Intelligence. Do animals think things out? Instinct. Do plants think? Are they sensitive?

Growth and Development. Keeping the race of animals and plants going. Development and growth in man and animals. Variation and heredity. New plants and animals.

(This next section may be left till the Fourth year if it is felt that the Third year is over-loaded.)

The inter-relations of life. The plant and animal kingdoms. The sun, plants, and animals. How plants and animals defend themselves. Parasites and partners. Bacteria and their work. Health and disease. Health and the community.

The heavens and their glory. This earth of ours — how did it begin? Why is it like it is? The sun — what is it? What we owe to it. Is there anyone living on the moon? The sun's family — the planets and their movements. The twinkling stars. Comets and meteors.

Fourth Year

How our town gets its electricity supply. How current electricity can be produced. Making use of this — a simple dynamo. How does a cycle-dynamo work? What is meant by A.C. and D.C.? Power stations. The grid system. Use of A.C. What is meant by induction. The induction coil. How do neon signs work? X-rays. What is a transformer? What is it for? What is meant by rectification? Conversion of A.C. to D.C. Charging accumulators.

How a wireless set works — a simple account of early discoveries leading up to a simple account of modern wireless.

Lightning and thunder. What are lightning and thunder? Static electricity. The lightning conductor.

Power and raw materials. Power — what are the chief sources of power? (a) Water power — early uses — water wheels, modern methods — turbines. (b) Wind power — sails, windmills, ships. (c) Coal and oil — steam power. How long will the world's supply of coal and oil last? (d) Electric power. (e) Hydro-electric power — The T.V.A. and other schemes. (f) Atomic power and its possibilities.

Raw materials. What are the most important raw materials? How are they distributed? Effect on ways of life.

Substitutes. Modern synthetic products and substitutes — synthetic rubber, sugar, from wood, etc. Synthetic quinine. Plastics — is the change from an iron age to an age of plastics coming about?

What is a calorie? Heat and temperature. How we measure the quantity of heat. What have calories got to do with food? Mea-

surement of food values. Nutrition — what constitutes a good meal?

Evolution. Have there always been living things on the earth? How did life begin? Were men and animals and plants thousands of years ago like the living things of to-day? The meaning of evolution. The evidence for evolution — (a) Evidence from plant and animal structure — study of facts upon which classification of animals is based suggests that different species may have arisen by modifications in some more or less remote ancestor. (b) In the rocks — evidence of continuous though gradual change. The evolution of the horse. (c) Evidence of the vestigial organs — e.g., tail bones, ear muscles of man, leg bones of whale and snake — now useless structures. (d) Evidence of the embryo — is this evidence to be accepted as correct?

What is meant by variation in species? Darwin and his work. More about Mendelism. What is meant by mutation? How do new species arise? Breeding new animals and plants.

In the Board of Education's *Handbook of Suggestions on Health Education* it is recommended that during the last year of 'Senior' school work the various topics in hygiene should be summed up in the following way. The pupil should know:

(a) How to keep himself healthy and clean (nose, ears, eyes, skin, teeth, bowels, etc.).

(b) How to render first aid in case of illness and accident (stings, cuts, burns, bruises, etc.).

(c) In the case of girls, how to do sick nursing and to prepare invalid food and to know something about infant care.

(d) Where the local clinics, welfare centres, and hospitals are situated.

(e) What to do when there is a case of infectious illness with a view to protecting the general public. Reasons for such precautions as are necessary should be realized.

(f) Something about important discoveries made in medical science in the past and at the present time and how they have benefited mankind.

(g) Something about National Health Insurance and the Hospitals Savings Associations.

The publications issued by The Health and Cleanliness Council, the Central Council for Health Education, the Ministry of Health, and the British Social Hygiene Council form excellent illustrative material for children of all ages.

. Every teacher should read *A Handbook of Suggestions on Health Education* (Board of Education publication, obtainable from H.M. Stationery Office), which in one hundred and ten pages contains comprehensive suggestions on the teaching of hygiene in all its branches, and all should see *Biology and Human Affairs*, published each term by the British Social Hygiene Council of Tavistock House, London, W.C.1.

CHAPTER X

'NATURE STUDY' AND PRIMARY SCHOOL SCIENCE

IN Nature study we aim at seeing, understanding, enjoying, and practically learning from the natural world round us,' says Professor J. Arthur Thomson.

Nature study is important for many reasons. It leads easily to later work in biology and the other sciences, it has practical utility in its relation to gardening and health; and above all, through it the child catches the spirit of the open-air, the colour and vigour of existence. The poets have expressed in verse and the musicians in song this feeling of unity with and in Nature. The idea of the beauty in Nature, both alive and inanimate, is one which should be fostered. There is more in Nature study than collecting — often a mere satisfaction of the acquisitive instinct — but useful enough in its way, or the dissection of flowers. These are only means to an end and that end is a fuller appreciation of and delight in Nature and a knowledge of the relationships of Nature. Young children interpret phenomena in terms of themselves and their own feelings. This animistic tendency can have a useful application to early work in Nature study; children are led to explore the life of the ponds, streams, and woods by reading books and poems and seeing plays with Nature for their theme, such as the works of Milne, Kenneth Grahame, Kipling, and Beatrix Potter. Nature study should foster a love of the countryside throughout the seasons, a desire to preserve its natural beauty and a wish to prevent its marring by litter or the destruction of the vandal.

Nature study provides useful correlations with drawing and painting lessons and colour teaching, clay and cardboard modelling; with poetry, simple music and dancing, and verse-speaking. Many scripture stories are full of the joy and wonder of natural phenomena.

Nature study should vary according to the locality, and every district will yield more material than is necessary for the work. Many primary schools possess gardens, and here very useful work

may be done. The primary school garden should be designed with a view to colour and form, and not merely cut up into small plots for growing crops. The garden will prove useful in other ways. Measurements of its various parts will give a basis for mensuration and area determinations; the constructive tendencies possessed by children may find their outlets in making rockeries, pools, sundials, and bird baths. In rural districts, Nature study should aim at showing the beauty and dignity of the daily work of the farm. In the towns there are difficulties which are not met with in the country, but aquaria and caged insects may be kept indoors and a more detailed study of the weather, bulbs growing indoors, trees in the streets, and vegetable and animal life in the parks and gardens could be made. Many hundreds of cinema films in the sub-standard gauges are available for Nature study work, and these, with short broadcast talks, may be fitted into the class work.

A seasonal method of treatment is useful, for the natural phenomena appropriate to each period of the year may be dealt with and the relations between the weather, the condition of the ground, vegetable and animal life may be stressed as a result of the child's observations. The seasonal method results in a better selection and grouping of the material.

A considerable part of the work may be done out of doors, but in the class room simple experiments may be performed to summarize the work, and to stress important points. A Nature calendar should be kept recording the changes in Nature day by day. This will include not only observations on plant and animal life but will mention wind, its direction and strength, cloud movements and what they tell us, hours of sunshine, ‘height’ of the sun, rain, hail, snow, fog; and wherever possible the interactions of vegetable, animal, and meteorological phenomena should be noted. More detailed observations should be illustrated by the child, and the year's recorded work bound into a booklet.

A larger and simpler Nature calendar should be hung on the wall of the class room. This may be in the form of concentric circles divided into twelve sectors each of which represents a month (or four sectors representing, spring, summer, autumn, winter respectively). The outer ring may contain coloured paint-

ings or drawings of flowers, fruit and vegetables appropriate to the particular month or season, the next ring would deal with animal, bird, insect, and fish life, and the inner ring with atmospheric conditions.

Unfortunately there is a tendency in schools to discontinue Nature study and simple science work at the age of nine and ten, but it is most important that there should be complete continuity in the course in science from the earliest days of the work throughout the whole school life of the child.

From the age of about nine the science work should be extended to include not only a more practical treatment of the Nature work but a simple study of some useful topics in physics and science in general.

This is the age when children ask 'Why and How', and simple experiments and descriptive lessons designed to answer questions connected with their interests should be given. Meccano models, Hornby trains, levers, pulleys, and simple mechanism are popular at the age of ten. Simple electric circuits and working models, toy cinemas, and 'magic-lanterns' are fascinating and may form the basis of lessons which will foster enthusiasm for later systematic work in post-primary schools. Again, easy work with sufficient pictorial and practical illustrations on simple astronomy will pave the way for fuller treatments in science and geography in later years. In the words of the Primary School Committee, 'No attempt should be made to build up an organized body of science at this stage; the aim should be to interest children in just those physical phenomena which they meet in their ordinary experience.'

SOME AIDS TO SCIENCE TEACHING

1. *Visits to Factories, Works, Museums, Gardens, etc.*

IN America a favourite way of teaching Science and some other topics is by 'projects'. In this country our method in the past has been to develop the first principles of the subject and to try to obtain conclusions or generalizations. After this we apply our generalizations to as many practical examples as time permits, which is usually not more than one or two. In this way we cover a good deal of ground in a short time and we claim that we develop the subject in a logical and systematic manner. This, as we have seen before, may tend to dullness. The school should be 'an idealized epitome or microcosm of the world', but the methods so often applied to science have no relation to the larger things which are continually taking place outside the school. We often claim that our method teaches more facts in a shorter time, and that examinations are ever present and their syllabuses have to be respected. In secondary schools this cannot be an excuse, for here the examinations, if any, are not the crippling affairs which sometimes destroy the teaching of the upper forms of the grammar schools. Even in the case of School Certificate and other examinations taken in the grammar schools, humanizing influences are already at work and in the future we may look forward to a tendency to differentiate between the particular examinations for entrance to universities and the tests of satisfactory achievement during the school course. In the U.S.A. (though it must be remembered that America is so vast that there is nothing approaching universality for any particular group of ideas) the 'project' method is popular. Examples of this in operation are to be seen in the excellent old book, *The Science of Everyday Life*, by Buskirk and Smith. A task, a voyage of discovery is decided on and the principles and methods involved are learnt or developed as the investigation proceeds. The number of 'projects' which can be fitted into a term is small, but it is claimed that what is lost in academic facts and the systematic development of the subject is more than balanced by the training in initiative, resource, and observation.

which result. Some European critics retort that the results are superficial, the standards of attainment are low, and the air of over-confidence and 'efficiency' produced is as misleading to the pupil himself as to the teacher and employer. As with 'heurism' a middle way is probably correct.

Factory and works visits from the points of view of fostering scientific inquiry, for providing a basis for possible 'projects', for supplementing work in the class room and laboratory, and for the development of local interest, should form a part of every science course. Many science teachers do not realize the extent of the possibilities which are afforded by the district in which they teach. Since electrical power has become so cheap and convenient, modern factories do not always advertise themselves with long chimneys belching smoke! The local directory will usually give some guide to the 'works' which are worth visiting, and most managers and authorities are not only willing but desirous of co-operating with the teacher. Many, indeed, supply interesting brochures and samples of materials and manufactured goods. Some large factories make a special feature of advertising along these lines and even issue cinema films, lantern slides, and literature for those who cannot make a personal visit. A county like Cornwall does not seem to yield so many opportunities for factory visits as do London and the Midlands, but even in the case of Cornwall an enthusiastic seeker will find a surprising amount of science applied in the local industries, and practically all districts throughout the country have water, gas, and electricity works and sewage farms. In rural districts, visits to farms, orchards, modern dairies, quarries, etc., will provide occasions which are at least as useful and interesting as the time spent at factories.

Much advertising literature is quite useful as a further adjunct to illustrations for science lessons. The publications of the Central Electricity Board, the Electrical Development Association, the Post Office, the various marketing boards and many other large scale organizations, with various commodities to sell, are attractive in the way the material is presented and are useful. Some of the smaller posters make excellent decorations for class room walls.

Most museum authorities realize that the student, tyro, or even

the child have at least as great a demand on the facilities as the connoisseur or expert. Many of our museums are organized from a simple educational point of view and a single visit is worth many theoretical lessons. The various South Kensington Museums are well known and in this the child in easy reach of London is fortunate. However, there are some excellent museums in the metropolis which are little known and the teacher who is organizing or encouraging visits should read the various booklets obtainable from His Majesty's Stationery Office describing the museums and their contents. Visits to the Zoo, including the Aquarium, and to Whippsnade Park will be particularly useful if the child is prepared for the experience, and if the work is followed up afterwards. Sight-seeing in itself does not achieve much. Although England does not rival Germany in the number of its museums for teaching purposes most of our cities and towns have something worth investigating; indeed, at such places as the National Welsh Museum at Cardiff the exhibits in zoology and geology could hardly be improved from the educational point of view.

Science rambles in search of the exhibits of Nature will yield information on zoology, botany, geology, and related subjects which will prove to be of the greatest value, provided that it is always connected with the science course.

2. *Pictorial Illustrations*¹

Pictures can be as useful and interesting as demonstration experiments in science teaching. Illustrations should be bold, direct and sufficiently large so that everyone in the class can see clearly. No attempt should be made to overload a picture with detail. 'One picture — one idea' should be the motto of successful pictorial illustration. The teacher should have a clear idea in his mind of the different psychological approach to the picture and the diagram, although it is possible to combine them.

Highly coloured illustrations of fish and birds have long been a feature of Nature study teaching, but these failed in the fact that simplicity and directness were sacrificed to detail and quantity. Posters issued, usually without charge, as advertisements for drugs,

¹ See the author's *Visual Methods in Education* (Blackwell).

electricity and electrical apparatus, gas and gas-tar products, steamships and railways are often excellent, and the illustrative material which was printed a few years ago by various electrical firms to mark the centenary of Faraday's discovery of electromagnetic induction was particularly effective. Illustrations of nearly all our major industries can be obtained by application to the manufacturers concerned.

Portraits of the great men of science, since the time of the Greeks, can be framed and hung in the class room, and it must not be forgotten that biologists should figure as prominently as the astronomers and physicists. The film strip projector, lantern, episcopes and cinema will always be useful for presenting pictures and they have the advantages that the picture is large enough to be seen by all; also it is the only visible thing in the room and thus attention tends to be directed to it and to nothing else. Nothing is likely to oust the popularity of the lantern slide as a form of illustration, and science teachers would do well to acquire the art of making good transparencies. At first sight the possibility of using an episcopes for projecting opaque objects and book plates would appear to make it more attractive than the optical lantern. (The epidiascope, if it is true to its name, should be capable of projecting both slides and pictures.) However, it must be remembered that the picture projected by the lantern is much brighter, needs a less powerful light, and the room need not be in absolute darkness. A useful lantern can be made in the school workshop quite cheaply, but an episcopes to be satisfactory is more expensive, it requires large aperture lenses, and a very powerful illumination. A lantern can be made to yield quite tolerable results with a good motor head-light bulb and a car battery, but no episcopes is satisfactory under these conditions.

The larger optical lantern will not readily be displaced from the science laboratory and lecture-room, but for many purposes the film strip projector which projects static pictures on 35 mm. film and the miniature lantern which takes small slides of overall size 2 in. square.

The number of good film strips suitable for science teaching is rapidly increasing, and it is possible for teachers to prepare their own strips or at least to provide the diagrammatic and pictorial

material from which they are made. These and other matters concerning visual methods of education are dealt with by the author in *Visual Methods in Education* (Blackwell, Oxford, 1950).¹

The sub-standard cinema film is becoming increasingly popular as an aid to other forms of pictorial education, but it is unlikely that it will ever be the sole medium, for often the advantage lies with a good set of lantern slides, film strip or film slides. Unless the school has a properly designed operator's box, in accordance with official regulations, non-inflammable films are necessary. The 16 mm. sound film (S.M.P.E.² Standard) is becoming normal for class room and mobile cinema work. Its use is entirely free from danger as the films of this type do not burn and there are no open arcs in the projector. With a good Bell and Howell or G.B. projector the film can be shown effectively to audiences of upwards of 800. A silver screen is more expensive than an ordinary white screen, it shows every uneven place in its surface and the brightness of the picture falls off when it is viewed from the side. If 'D.I.N.' films (which have a sound track on the opposite side of the film to that of the S.M.P.E. type) are used a reversing mirror or prism will be required, or projection from the rear on to a translucent screen will solve the difficulty. Such projection is often used by teachers for small pictures: the projector is placed at the end of the teacher's bench and the beam strikes a vertical mirror placed at an angle of 45° both to the line of the beam and to the translucent screen, which is placed at the front of the teacher's bench. Some schools have a number of rooms which have been adapted for projection purposes, with proper attention to ventilation, black-out, and electrical devices both for the projector and the lighting system. Special care is needed in threading the film in the projector ('lacing-up') and it need not be pointed out that scrupulous care must be taken to avoid dirt or grit being carried by the film or contaminating the 'gates' of the projector.

¹ A useful practical account of the methods by which a teacher may make these miniature transparencies is given by C. H. Bailey in an article entitled, 'How to make film strip and miniature lantern slides using simple apparatus', in the *School Science Review*, No. 110, October 1948. In the same periodical, No. 112, June 1949, W. E. Pearce gives an account of the manufacture and use of small apparatus for giving projected demonstrations of physics experiments (e.g. colour combinations, electricity and magnetism) by using the film strip projector.

² Society of Motion Picture Engineers.

The Board of Education pamphlet 'Optical Aids' (H.M.S.O.) contains some excellent information concerning the arrangement of projectors, safety devices and projection rooms.

The film should be used as an integral part of the lesson and too long a session of projected films fails in its purpose. Short films can be used for emphasizing points in the special scientific studies, and longer films of a more general type are of great value in assisting 'recognition' or 'background' science. The control which the film has over size, speed, point of view, constructive movement, isotype and moving diagram, emphasis, 'montage', etc., is excellent in science teaching. Film technique, particularly high-speed, slow-speed and photo-micrography are of great assistance to scientific research. Many teachers will remember the film showing the growth of malignant cells made by Canti. Teachers should join a scientific film society where this is possible. Much time can be wasted by the indiscriminate projection of films, purporting to be of educational interest and teachers should make a point of seeing the film beforehand, making notes and rejecting all unsuitable material. If the picture is projected on to a sheet of drawing paper, at the bottom of a box turned on its side and painted dead black internally, the film can be 'run through' in broad daylight. The British Film Institute, 164 Shaftesbury Avenue, London, W.C.2,¹ has catalogued and critically considered all educational films and acts as a clearing house in these things. It can give authoritative advice on projectors and other film matters. The periodicals *Documentary News Letter* and *The Educational Film Review* contain useful information. Many of the best 16 mm. non-'flam' sound films of scientific interest can be borrowed free of charge from the Central Film Library at the Imperial Institute, S.W.7. This collection also contains copies of such films as those made for various ministries, and such firms as I.C.I. Some hundreds of new films have been made during the war and the production of 'background' scientific films is certainly increasing. Amongst outstanding productions, which can be obtained without hiring charge, are those on every aspect of agriculture, gardening, health of animals, milk production, etc., made for the Ministry of Agriculture, Plant Protection Ltd., or I.C.I.; the films on medical science, hygiene,

¹ The address of the Scientific Film Association is 34 Soho Square, London, W.1.

physiology, etc., such as those on 'M. and B. 693' and the new films made for the Central Council for Health Education, the Ministry of Food and Ministry of Supply, the films on prefabrication, housing, soil erosion, penicillin, blood transfusion, petroleum, the various industries of this and other countries, gas, electricity distribution. A few outstanding productions of recent years are:

T.V.A. — The Tennessee Valley Scheme.

Men of Africa — Science and tropical diseases.

Colour — An I.C.I. film in colour.

Mass Radiography — Detecting tuberculosis in its early stages.

A.B.C.D. of Health — Vitamins.

World of Plenty — The world food problem.

The story of Penicillin.

Great-circle — Great-circle aerial navigation.

Other films may be rented at reasonable rates from the Gaumont-British, British Film Institute and Kodak libraries. The Nature study films made by Mary Field and others are particularly interesting. Sometimes a full-length commercial picture with scientific interest may be seen at the cinema, and if regarded critically may be quite useful. Such productions as 'Pasteur', 'Dr. Ehrlich's Magic Bullet', 'Thomas Edison', and 'Madame Curie' were not without some educational value.

The Micro-Projector

Although work with the micro-projector may be termed visual rather than pictorial illustration it may be well to mention it here. Microscopy as a technique is far too difficult a subject for secondary school work, but the instrument, even if of low power, is a real necessity if serious biology teaching is to be done. A knowledge of the structure of plants and animals, and the examination of small creatures are essential to quite elementary work in biology. Even a single microscope is considered a luxury in some schools, and the teacher can make the most of a single instrument by using it as a micro-projector. A low power microscope can be utilized as a micro-projector by adding to it a lamp and stand holding a lamp house containing a small 50 watt bulb, and fitted with a tiny condenser such as is found in the smallest types of sub-standard cinema projector. However, a perfectly satisfactory micro-projector can,

be bought for a price ranging from £20 to £30 and when occasion arises the microscope part can be used normally. The instrument can be worked from accumulators or from the mains and a circular picture up to three feet diameter should be obtained. This saves the inconvenience and waste of time necessitated when the members of a class file separately past a microscope, only obtaining a glimpse of the subject. The projector has the advantage of giving the idea of the solidity of the object by focusing on different parts, but observations on small living creatures can only be carried out by using the microscope in the ordinary way as the heat of the lamp is fatal to the animal; and in any case care should be taken not to destroy the ordinary prepared microscope slides by allowing the temperature to rise too much. The micro-projector has many uses apart from biology: chemistry and physics will yield suitable illustrative material quite often.

3. *Broadcasts*

In recent years and particularly since the war immense strides have been made in the technique of school broadcasting. Even in the case of children who have low verbal ability, either through lack of general intelligence or through deficiency in some specific factor governing the use and understanding of words, broadcast interviews and discussions, dramatic interludes, illustrations in sound and other devices will go far to overcome the difficulties attending a twenty-minute period of pure exposition, which has become the exception rather than the rule. The broadcast talk is now broken up in one way or another. There may be one or more dramatic interludes, often used to bring vividly to the imagination of children outstanding incidents in the history of discovery. Or the programme may include 'actuality', when the audience is taken to some institution where scientific discoveries are being made or applied, and hears an eye-witness description or an 'on-the-spot' discussion (complete with appropriate sounds) of what is going on there. This is the type of technique which would generally be employed in programmes concerning a meteorological station, a plastics factory, a pasteurization plant, an agricultural research station, etc. Sometimes the device of a 'time-machine B.B.C. observer in the past' (as in the series 'How things began') or

even in the future (as in the series 'Science and the Future'), has proved very effective. Such devices provide a genuine extension of the range of children's experience. They do so (like the silent film), through the medium of one sense only, but imagination does much towards completing the experience, so that in a way the audience feel themselves to be really present in Edison's laboratory, a coal-age forest or a modern industrial plant. These developments of the last few years mean that in science, as in other subjects, radio is now being used freely in terms of its own special properties as a medium and not simply as a means of putting the expert at the disposal of the school. There is still a place for the 'straight' talk by the expert and this is still sometimes used occasionally in general science and more often in 'The Practice and Science of Gardening'.

The B.B.C. series of general science talks is intended for the schools formerly known as Modern Schools. In view of the difficulties of staffing and equipment to which these schools have been subjected during the war, many of them have come to look to the broadcasts for a framework round which some kind of war-time science syllabus can be built.

Science teachers should become conversant with the work of the School Broadcasting Department of the B.B.C. and the Central Council for School Broadcasting.

There follows a list of General Science Talks for schools given recently:

GENERAL SCIENCE

Autumn Term 1940

Unit I. Microbes as Friends and Foes (by R. Palmer)

- (1) Living Things come only from Living Things.
- (2) New Worlds.
- (3) How Things go Bad.
- (4) Microbes and Disease.
- (5) Keeping out Germs.
- (6) Fighting Germ Carriers.
- (7) Microbes as Friends.

Unit II. Sources of Power (by J. A. Lauwerys)

- (1) Energy from Moving Air.
- (2) Water Mills — Power from Moving Streams.
- (3) Coal as a source of Power.
- (4) Oil to move Wheels.
- (5) Electricity in the Service of Man.

Unit III. How Aeroplanes Fly

- (1) Conquering the Air, by J. A. Lauwerys.
- (2) Flying an Aeroplane, by Ralph Michaelis.

*Spring Term, 1941**Unit I. Reproduction and Growth* (by Richard Palmer)

- (1) You are made of Cells.
- (2) How Eggs start to Develop.
- (3) The Importance of Egg-Shells.
- (4) How Mammals take care of their Young.
- (5) Nature and Nurture.
- (6) Healthy Growth.
- (7) War and the Germ.

Unit II. Man and Metals (by J. A. Lauwerys)

- (1) The Tin Islands.
- (2) The Noble Metals.
- (3) The Base Metals.
- (4) Steel.
- (5) Metals and the Future.

*Summer Term, 1941**Unit I. Food and Health* (by Richard Palmer)

- (1) What is Food Made Of?
- (2) Food as Fuel.
- (3) Food and Growth.
- (4) About Vitamins.
- (5) More about Vitamins.
- (6) Food and Health in the Machine Age.

Unit II. The Thirst of the Cities (by J. A. Lauwerys)

- (1) Finding Water.
- (2) Storing Water.
- (3) Bringing Water to the City.
- (4) Purifying Water.
- (5) Using Water.

Autumn Term, 1941

Unit I. Man Defends Himself (by Professor Doris Mackinnon)

- (1) The Balance of Nature.
- (2) Man Defends his Crops.
- (3) Man versus Rat.
- (4) Man versus Worm.
- (5) Killing Germs.
- (6) The Body's own Defences.
- (7) Man versus Mosquito.

Unit II. Making Light (by J. A. Lauwerys)

- (1) Campfire and Torch.
- (2) Oil Lamp and Candle.
- (3) Gaslight.
- (4) The Gas Mantle.
- (5) The Coming of Electric Light.
- (6) Electric Light To-day and To-morrow.

Spring Term, 1942

Unit III. Reproduction and Growth (by Richard Palmer)

- (1) You are made of Cells.
- (2) How Eggs start to Develop.
- (3) The Importance of Egg-Shells.
- (4) The Young Mammal is Born.
- (5) Healthy Growth.

Unit IV. The Conquest of Materials (by J. A. Lauwerys)

- (1) Fibres, Old and New.
- (2) Getting and Making Oil.
- (3) Dyes, Natural and Artificial.
- (4) Plastics.
- (5) A Tin Can.

*Summer Term, 1942**Unit V. Using Our Senses* (by Richard Palmer)

- (1) Using our Eyes.
- (2) Using our Ears.
- (3) Using our Fingers.
- (4) Science Improves on the Senses.

Unit VI. Notes and Noises (by J. A. Lauwerys)

- (1) How Sound is Carried.
- (2) Ways of Making Sounds.
- (3) More Ways of Making Sounds.
- (4) How Fast Does Sound Travel?
- (5) The Quality of Sounds.
- (6) Recording Sounds.
- (7) Sound in War.

*Autumn Term, 1942**Unit I. Science and the Doctor* (by Richard Palmer)

- (1) Feeling your Pulse.
- (2) Taking your Temperature.
- (3) Sparing us Pain.
- (4) What's going on Inside?
- (5) Taking a Swab.
- (6) Prevention is Better than Cure.

Unit II. Other Worlds (by G. P. Meredith)

- (1) The Earth from Outside.
- (2) A Journey to the Moon.
- (3) A Close-Up of the Sun.
- (4) On the Trail of a Comet.
- (5) Finding where you Are.
- (6) Galileo and the First Telescope.

*Spring Term, 1943**Unit III. Heat in the Home* (by J. A. Lauwerys)

- (1) Fire-Lighting and Fire-Fighting.
- (2) How Heat Travels.
- (3) Melting and Boiling.
- (4) Making Things Colder.

- (5) Measuring Heat and Temperature.
- (6) What is Heat?
- (7) Humphry Davy and the Safety Lamp.

Unit IV. Reproduction and Growth (by Richard Palmer)

- (1) What are you made of?
- (2) How Eggs start to Develop.
- (3) The Importance of Egg-Shells.
- (4) The Young Mammal is Born.
- (5) Growing Up.

Summer Term, 1943

Unit V. Materials for the Home (by J. A. Lauwerys)

- (1) Four Walls and a Roof.
- (2) Metals.
- (3) The Story of Glass.
- (4) Science and the Potter.
- (5) How Fibres Behave.
- (6) The House of the Future.

Four Special Talks

- (1) Animals, Plagues, by Cyril Bibby.
- (2) Michael Faraday and the First Dynamo, by Dorothy M. Turner.
- (3) Asking One Question at a Time — I, by Richard Palmer.
- (4) Asking One Question at a Time — II, by Richard Palmer.

Autumn Term, 1943

Unit I. Great Discoveries

- (1) Franklin and the Lightning, by A. J. Mee.
- (2) Classifying Living Things, by Cyril Bibby.
- (3) Dr. Wells and the Dew, by R. K. Robertson.
- (4) Roentgen and X-Rays, by Dorothy M. Turner.
- (5) Fighting Scurvy, by F. R. Elwell.
- (6) The First Balloonists, by J. A. Lauwerys.

Unit II. Thinking It Out (by Patrick Meredith)

- (1) Thinking It Out — I
- (2) Thinking It Out — II

Unit III. Using Our Senses (by Richard Palmer)

- (1) Using our Eyes.
- (2) Using our Ears.
- (3) Using our Fingers.
- (4) Science improves on the Senses.

*Spring Term, 1944**Your Body and Its Growth*

- (1) What are you Made of? by Richard Palmer.
- (2) How Eggs start to Develop, by Richard Palmer.
- (3) The Importance of Egg-Shells, by Richard Palmer.
- (4) Some Advantages of being a Mammal, by Richard Palmer.
- (5) The Newborn Baby, by Philip Eggleton.
- (6) The First Two Years, by Philip Eggleton.
- (7) Growing Up — I: Food, by Philip Eggleton.
- (8) Growing Up — II: Glands, by Philip Eggleton.
- (9) Feeding the Body's Engines, by Philip Eggleton.
- (10) What's your Horse Power? by Philip Eggleton.
- (11) Getting Skilful, by Richard Palmer.

*Summer Term, 1944**Science and the Future*

- (1) The Home of the Future.
- (2) Building the House.
- (3) Planning the Town.
- (4) Air Travel and Transport.
- (5) New Sources of Power.
- (6) A Week-End in the Arctic.
- (7) Food.
- (8) Farms of the Future.
- (9) Keeping Well.
- (10) Lots of Leisure — What shall We do with it?

*Autumn Term, 1944**Things Around Us*

- (1) Iron and How We Get It, by Christopher Hanson.
- (2) Steel for Strength, by Christopher Hanson.

- (3) Bricks and Walls, by B. G. Whitmore.
- (4) Wood, by Silvia Goodall.
- (5) Materials for Clothing, by Helen Coppen.
- (6) More Materials for Clothing, by Helen Coppen.
- (7) Paper and Ink, by T. J. S. Rowland.
- (8) Glass for the Home, by J. A. Lauwerys.
- (9) More about Glass, by J. A. Lauwerys.
- (10) Paint, by J. A. Lauwerys.
- (11) Man and Materials, by J. A. Lauwerys.

Spring Term, 1945

How Your Body Works

- (1) Your Body as a Whole, by Richard Palmer.
- (2) Muscles and Bones, by Cyril Bibby.
- (3) Working in Harmony, by Cyril Bibby.
- (4) You and Your Food, by Cyril Bibby.
- (5) What happens when you Breathe, by Cyril Bibby.
- (6) Your Transport System, by Cyril Bibby.
- (7) Glands and Growth, by Richard Palmer.
- (8) New Cells and New Human Beings, by Richard Palmer.
- (9) How a Human Baby begins to Develop, by Richard Palmer.
- (10) The Baby is Born, by Richard Palmer.

Summer Term, 1945

- (1) The Speed of Sound — I, by Alexander Wood.
- (2) The Speed of Sound — II, by Alexander Wood.
- (3) Bending Light — I, by J. A. Lauwerys.
- (4) Bending Light — II, by J. A. Lauwerys.
- (5) Living Things come only from Living Things — I, by Anthony Barnett.
- (6) Living Things come only from Living Things — II, by Anthony Barnett.
- (7) Electricity and Chemistry — I, by Christopher Hanson.
- (8) Electricity and Chemistry — II, by Christopher Hanson.
- (9) Gases have Weight — I, by J. A. Lauwerys.
- (10) Gases have Weight — II, by J. A. Lauwerys.

Here are some notes for the class teacher on 'Science and the Future', Summer Term 1944.

Broadcasts in the Autumn Term were concerned mainly with scientific method and the story of scientific study. In the Spring Term we dealt with the scientific study of a single subject — the pupil's own body. This term we take again a wider view and look forward to the future. Applied science has given us a world rich in possibilities for human welfare and fraught with dangers that challenge human wisdom. As science enlarges our range of choice it increases our responsibility to choose well. The citizens of to-morrow should know something of man's new powers and the problems and opportunities that lie ahead.

The aim of these broadcasts on 'Science and the Future' is to capture interest and fire the imagination rather than to impart detailed knowledge. In so wide a field the latter would present an impossible task. The success of the broadcasts will therefore be measured by the activity to which they lead — the search by the children for further information in libraries, museums and exhibitions; the collection of cuttings from newspapers and magazines; and a new interest in scientific films and broadcasts. Any information that teachers can give about such follow-up activities would be a most welcome contribution towards future planning.

As a rule each broadcast will fall very roughly into three parts. It will open with a discussion of some aspects of applied science to-day. These current trends will be explained at a very simple level, assuming little or no previous knowledge. Then our observer will go in imagination into the future and see where these current trends may lead. In this way the 'growing points' of applied science to-day should become sufficiently magnified to excite the interest of children and give them a sense of living in a rapidly changing world. The observer episode should also serve to relate scientific advance in a realistic way to the daily lives of ordinary people. This theme and others will be taken farther in the third part of the broadcast. These changes may be *possible* but do we *want* them? What other possibilities are there? So planned, each broadcast should offer to the teacher a wide field of choice for follow-up discussion, on science, on current affairs, and on human values. The following notes are intended to give the

teacher some idea of the scope of each broadcast and to suggest books that may be helpful.

Notes on the Broadcasts

(1) *The Home of the Future*

An easy introductory broadcast dealing mainly with the inside of the house and its equipment. Plastics, synthetic textiles and other new materials. New methods of lighting. Labour saving through good design in general plan and in small but important details. Television. A library on microfilm. Books: Hatfield: *Inventions* (Pelican); Yarsley and Couzens: *Plastics* (Pelican); Houses we live in (H.M.S.O.); Bertram: *Design* (Pelican).

(2) *Building the House.*

The actual structure of a house — advantages and disadvantages of bricks and mortar, reinforced concrete and prefabrication. Air conditioning. Houses versus flats. Books: Badmin: *Village and Town* (Penguin); Boumphrey: *Your House and Mine* (Allen & Unwin); Tubbs: *The Englishman Builds* (Penguin).

(3) *Planning the Town*

Some of the present problems (ugliness, traffic congestion, road deaths, lack of community centres, smoke pollution, ribbon building, lack of greenery) and some suggested solutions. Transport inside the town and across country. Books: *Rebuilding Britain* (Royal Institute of British Architects) contains a useful book list. Tubbs: *Living in Cities* (Penguin); Mumford: *The Culture of Cities* (Secker & Warburg); Huxley, T. V. A.: *Adventures in Planning* (Architectural Press); *Our Birmingham* (Cadbury); *Changing Britain* (Cadbury).

(4) *Air Travel and Transport*

How aeroplanes fly. Jet propulsion. Stratosphere flight and its advantages. Great circle air routes, e.g. over the polar regions. The future of the goods plane and some sidelights on the effect of rapid and fairly cheap air travel on people's lives. Book: Davey: *Interpretative History of Flight* (H.M.S.O.).

(5) *New Sources of Power*

Present-day *sources* of power — coal, oil, and water. Electricity as a means of *transmitting* power over long distances. The world's mineral reserves of oil will soon be exhausted. Coal reserves will still last a long time at the present rate of consumption, but coal may eventually need to be conserved as a compact source of organic materials for the making of plastics and other synthetic materials. What new sources of power are within our reach?

Books: Vowles: *The Quest of Power* (Chapman & Hall); Riley: *The Age of Power* (Sidgwick & Jackson); Andrade: *Engines* (Bell).

(6) *A Week-End in the Arctic*

Control of temperature and other environmental factors are already making the tropics and the polar regions more habitable. A current example is the Soviet development of the Arctic coast of Siberia. There are extensive coalfields in the Antarctic continent and considerable mineral resources in Northern Canada. How soon may these be fully exploited? And what other industries may be carried on in the polar regions? Book: Brown (translator): *Voyage of the Chelyuskin* (Routledge).

(7) *Food*

Dehydration, canning, vitamin additions, and synthetic food-stuffs — have these come to stay or will rapid transport and other advances make them unnecessary except in emergency? Books: Drummond and Wilbraham: *The Englishman's Food* (Cape); Mar-rack: *Food and Planning* (Gollancz); Bacharach: *Science and Nutrition* (Watts).

(8) *Farms of the Future*

Current trends in agriculture include extensive mechanization, soil improvement, the production of new varieties of plants and breeds of animals, the biological control of pests, and the vernalization of seeds. The future may see the further development of two sorts of farms — intensive cultivation on relatively small mixed farms for supplying local needs, and, in some countries, large-scale production of wheat and other crops for export. In this type of agriculture the aeroplane may come to be used as widely as the

tractor is to-day. BOOKS: Easterbrook: *Machines on the Farm* (Pitman); Nicol: *Biological Control of Insects* (Pelican); Nicol: *Microbes by the Million* (Pelican); Jacks and Whyte: *The Way of the Earth* (Faber & Faber).

(9) *Keeping Well*

Early diagnosis, immunization, and new germ-killing drugs are helping us to bring many diseases under control. But some disease organisms, especially the viruses, are able to adapt themselves to our methods of attack, which have to be varied accordingly. However rare some of our present diseases become, scientific medicine will have to keep on the watch. BOOKS: Bourne: *Health of the Future* (Pelican); Pearce and Crocker: *The Peckham Experiment* (Allen & Unwin); Drew: *Man, Microbe and Malady* (Pelican); Roberts: *Everyman in Health and Sickness* (Dent); Smith: *Beyond the Microscope* (Pelican); Horder: *Britain's Health* (Pelican); *Health Education Journal* (Central Council for Health Education, quarterly 1s. 6d.).

(10) *Lots of Leisure — What Shall We Do With It?*

New methods of production will result in more leisure for everyone. Recreation should be regarded as part of the pattern of living. This broadcast will show some of the many and varied ways of using leisure in the future — travel, crafts, research, civic responsibility, heroic adventure — and just fun.

General Book List

Bernal: *The Social Function of Science* (Routledge); Bliven: *Men who Make the Future* (Pilot Press); Crowther and Others: *Science and World Order* (Penguin); Furnas: *The Next Hundred Years* (Cassell); Haldane: *Science and Everyday Life* (Pelican); Hatfield: *Inventions for Everybody* (Pitman); Hawks: *Triumph of Man in Science and Invention* (Jack); Hogben: *Science for the Citizen* (Allen & Unwin); Huxley: *Scientific Research and Social Needs* (Watts); Mumford: *Technics and Civilization* (Routledge); Palmer: *Science and World Resources* (Fact No. 21); Samuel: *An Unknown Land* (Allen & Unwin); *Science Looks Ahead* (Oxford University Press); Stapledon: *Last and First Men* (Pelican); *Triumphs of Engineering* (Odhams); Wells: *When the Sleeper Awakes*; Wells: *The Shape of Things to Come*; Wells,

Huxley and Wells: *The Science of Life* (Cassell); *Discovery* (Monthly, 1s. 6d.).

Although the broadcasts are usually intended for children other than those in the senior forms of grammar schools, the course on 'Some Modern Techniques of Social Investigation' given for sixth forms in the Autumn Term 1944 was an excellent foundation for those studying social sciences, and a good background to the necessary scientific knowledge of all responsible citizens.

CHAPTER XII

SCIENCE ROOMS, LABORATORIES, AND THEIR EQUIPMENT

THAT a large science room is a necessity for every type of post-primary school has been recognized for some years. Where new schools are built to provide accommodation in accordance with reorganization schemes a laboratory is generally included. Usually the teacher has to do the best he can with the room available, but where new buildings are being erected, every effort should be made to see that the science room is a satisfactory one. Space is more valuable than elaborate fittings and the standard large science room of 960 sq. ft. (for example, 24 ft. by 40 ft.) stipulated by the Ministry of Education should be adopted where possible. Heavy fixed benches with elaborate draining arrangements of the type which were to be seen in the older chemistry laboratories are both unnecessary and undesirable. Movable benches which can be taken away altogether, and which upon occasion can be placed against one another, are much more useful. Gas can be brought from the ceiling, and electricity from the sides of the room when required. If long fixed benches are arranged to go along two sides of the room this will give plenty of room for water, sinks and permanent fixtures. It is desirable that the teacher's bench should be raised on a platform and be fitted with sink, several water taps, and gas. Storage room is usually an ever present trouble in science rooms which have had to be limited in space, or which have been adapted from existing and usually inadequate rooms. It is then necessary to use cupboards beneath the benches for storing apparatus and this should always be avoided where possible and not only on account of the pupils' leg room! A separate store room is a real necessity and the expense and trouble of providing it, where this can possibly be done, is amply repaid by the gain in efficiency of working and in the preservation of apparatus. Cupboards, some of which should be fitted with strong locks, can be arranged on the laboratory walls so that they neither obscure the light nor look un-

sightly. In the majority of modern schools the science room will have to serve for biological as well as for physical subjects and in addition it will probably have to be used as a demonstration room. All the windows should be fitted with good blinds, so that the room may be darkened in order that the projection lantern, the episcopes, the cinema, and micro-projector may be used. In the case of the lantern complete darkening is not essential but with the other instruments it is very necessary, or otherwise the results are unsatisfactory and cause eye strain. Few modern school laboratories contain exposed roof beams. These are very useful as much trouble may be saved by utilizing them for suspending apparatus used in physics and biology. Even where they do not exist some arrangements should be made whereby hooks and beams can be used. Such an arrangement above the teacher's demonstration bench is very useful for a piece of apparatus can often be suspended from above, and it saves bulky stands and other structures which obscure the vision and uselessly fill space on the demonstration bench. It is surprising that overhead suspensions are so little used at present.

Most school laboratories are supplied with electricity,¹ and alternating current at about 250 volts is becoming general. Nevertheless, it is doubtful whether the best use of electricity in the laboratory has yet been attained. It is a simple matter to wire both of the sides of the science room and to supply ten pairs of terminals at convenient tapping points. For experiments in light, when small enclosed 12 volt bulbs will serve admirably as a source of illumination, the A.C. main supply may be transformed to A.C. at 12 volts and fed into the wiring at the side. This is a perfectly safe procedure. Such a transformer can be made for about fifteen shillings or less, from soft iron laminations (specially prepared to give great permeability and small magnetic losses), and a couple of suitable tapped windings on fibre formers. Usually, however, direct current at from 2 to 12 volts is required and a few accumulator cells

¹ A unit capable of providing A.C. or D.C. at 40 amperes with smooth control of voltage from 0 to 14 volts, and 32 amperes from 14 to 18 volts, costing about £60, has been designed by Sir Graham Savage and C. E. Belcher and has been supplied to L.C.C. Schools. The unit employs a bridge-connected funnel-cooled selenium cell stack for the production of D.C. with primary control of the A.C. voltage by means of a variable ratio auto-transformer. It is described in *The School Science Review*, No. 112, June 1949.

say of 200 ampère-hours capacity each can, by a simple switching arrangement, be made to yield voltages between 2 or 12 or more (reckoning 2 volts per cell). Switches can easily be wired so that any one cell does not get more than its fair share of the work if the lower voltages are used most often. It is of course necessary to mark each pair of terminals positive and negative when direct current is to be tapped off. Various types of rectifiers have been bought or made in schools for charging batteries. Even the smaller rotary type usually proves too large and expensive for secondary school work, but it is an interesting piece of apparatus for teaching work in electricity. The smallest types of rotary or vibratory transformers are usually noisy and inefficient and soon wear out. The electrolytic cell method known as the Noden valve is also uncertain and not permanent in action, whereas thermionic valve and small mercury vapour rectifiers are so cheap and reliable that they can always be recommended. On a large scale rectifiers of this type (Hewittic rectifiers) are used day and night in connection with electricity distribution and the Grid, and if the smaller valve rectifier is bought for accumulator charging it can be used in fairly senior classes to demonstrate a number of important principles of great practical utility.

The fixed side benches in the laboratory are worth special consideration, and these should be as wide as is conveniently possible, as they will have to hold apparatus used in experiments which have to be left for days or weeks, and such things as aquaria, vivaria, etc. In biology a small greenhouse is a boon but a Wardian case may be built into one of the windows, and if this is not provided when the school is built it is possible to make one very cheaply in the handicraft workshops. Aquaria are better placed away from windows and in fact fish benefit by being kept away from bright light. A fume cupboard finds little appropriate use in central school work and elaborate arrangements for balances are not required. One or two fairly good chemical balances costing a few pounds each should be kept in the storeroom but for the ordinary work a variety of spring balances graduated on the Metric system will prove to be both cheaper and quicker to use.

Many science teachers still have to labour under difficulties as regards suitable rooms, and yet it is still possible to do very useful

practical demonstrations even without gas, water, and electricity. A supply of water can be obtained by syphoning from a tank or bucket placed on the top of a cupboard. Primus paraffin stoves and small spirit lamps will fulfil many of the functions of Bunsen burners; and electricity up to 12 volts can be obtained from a car battery. Often there is electricity available, but no gas or water. Electric heating 'elements' can be adapted for many of the experiments in science which usually need gas. Good apparatus and laboratories are a splendid convenience but they must not detract from the real spirit of science. All the great research workers in science have had to use their ingenuity to make pieces of apparatus, and often to press everyday objects into their service. Pictures of Davy, Faraday, Priestley, Cavendish, and many others working in their 'laboratories' give useful impressions of the homely apparatus which they used, and even in many modern research laboratories much thought and trouble are expended in making apparatus; for instance, in the cotton research laboratories at the Shirley Institute, near Manchester, a great deal of apparatus is made from Meccano parts.

Detailed accounts of the construction of apparatus from first class new materials are beyond the scope of this book, nor is this often required or possible in school work. On the other hand the teacher with vision, resource, ingenuity and some manual skill will be able to find useful common objects from the cheap stores, obsolete materials in builders' and plumbers' and breaking-up yards, in packing cases, jars and tins, in secondhand wireless, camera, and other shops, which with a little new material he can readily adapt to form valuable and serviceable apparatus. Moreover, there are many advantages in this besides the saving of money:

1. A greater psychological control results by using home-made apparatus.
2. The work can be done on a larger scale with real things, and thus the applications to life and things around us are more obvious than when models or highly artificial and expensive apparatus are used.
3. The child is encouraged to experiment for himself as a hobby.
4. There is a genuine training for the exercise of resource,

ingenuity, vision, and manual skill which are all useful qualities in everyday life.

5. The child obtains a glimpse of the tasks and difficulties of the great scientists and is nearer to the position of an actual discoverer than would result from the strained 'heurism' of the laboratory.

Mechanics

Experiments should be done on as large a scale as possible and it is often cheaper to use actual apparatus such as pulleys and small engines than models of them. A garage, 'motor-breaking' yard, marine-store dealers will often yield treasures in the shape of bicycle wheels, friction brakes, springs, levers, geared cog wheels. Indeed, the chassis of an old car may be bought for a few shillings and it can be used as the basis of a number of lessons on engines and power. The teacher should also be on the look out for old magnetos, car dynamos, volt meters, trembler coils, etc., which can be used for work in electricity. On a smaller scale old clocks, mechanical toys, and gramophone motors can often be adapted for useful purposes. The teacher should make a number of spring balances both of the extension and compression patterns, and many uses can be found for Meccano parts. Stands for experiments in mechanics and for many other purposes are readily made from vertical lengths of $\frac{1}{2}$ in. to $\frac{5}{8}$ in. dowelling fixed into holes in a base board of wood. A number of small screw-in hooks can be used for attaching the apparatus to the stand. Very serviceable gyroscopes can be purchased for eighteenpence and such instruments will serve to demonstrate gyro-compasses and the stabilization of moving objects by gyroscopes.

Weights can be made from scrap iron, melted lead, and other materials found in 'junk' shops where obsolete or damaged material is for sale. Builders' and plumbers' yards will yield a number of useful objects which can be readily adapted for use in the laboratory.

Heat

Apparatus for showing expansion of metals, liquids, and gases and for the demonstration of different rates of conduction in metals, is easily made up from simple things found in all labora-

ories. A few simple chemical thermometers should be purchased and calibrated.

If a small petrol engine is not obtainable, making models of various types of heat engines are usually favourite tasks for metal workshops. Apparatus for showing the mechanical equivalent of heat is not difficult to construct if a small electric motor is available for driving the friction device. A simpler way in secondary schools is to measure the heat in terms of electric energy. An ordinary 60 watt electric bulb can be immersed in water in a large tin (calorimeter) and the rise in temperature over a period of time noted. It is assumed that all the electrical energy is converted into heat. The construction of a thermopile and its use have already been indicated — such an instrument is useful for studying radiation. The practical work should aim at explaining the functions of heat in our lives; for example, conduction and clothing, radiation and clothing, ventilation, heating from coal, gas, and electricity. Central heating may be demonstrated by a model apparatus made from a large doll's house (or from packing cases), some tins, and pieces of 'compo' tubing.

Light

Lens holders — made by bending strips of tin.

Lamp houses — these are very useful for experiments on reflection, refraction, and dispersion. Small cigarette or other tins are blackened inside and out, a slit is cut in the side, and a hole sufficiently large to hold a small lamp holder is punched in the bottom. With a 12 volt current, which may be used without fear of shock, small sixpenny headlight bulbs give an excellent source of light.

Wave trough — a glazed window frame is admirable for this purpose.

'Universal' lantern — the lantern body should be made of sheet tin or iron riveted or screwed together. It is fixed at the end of a long base board and other fittings may be added as desired — condenser, cells or slide carriers, objective, prism, colour filters, etc.

Episcope

The type of episcope which can be made depends almost entirely on the lens which can be afforded. A sheet iron body is best and

powerful sources of light with reflectors should be provided. The British Optical Company of Birmingham makes excellent lenses for this purpose.

Colour Apparatus

This is always attractive and easy to make. Some has been indicated in the section on light. A suitable vertical spinning wheel for demonstrating Newton's and other colour discs and other effects can be made from Meccano parts. Pictures showing colour harmony, the Ostwald colour wheel, are easily obtained from pigment manufacturers and relate the work to our lives, the decoration of rooms, colour schemes, etc.

Glass cells, water lenses (from watch glasses) can readily be made if the teacher acquires skill in the use of the various cements which are sold by the scientific supply houses.

Pin-hole and lens cameras can be made from small wooden boxes (it is probable that in the future sufficiently good lenses will become quite cheap).

Kaleidoscope — two or three long slips of mirror placed in a round tube with pieces of coloured glass loosely enclosed at the end of the tube. Small pieces of mirror may be adapted for a number of purposes — a periscope, a sextant.

Persistence of vision may be demonstrated by means of the revolving disc.

A small cinematograph camera and projector can usually be borrowed, even if they are not possessed by the school.

Electricity

Insulating stool. — Four glass jars used as the legs to support a drawing board.

Electrophorus. — Shellac is melted into a large round tin lid. The disc may be made of tin smoothed at the edges and a stick of sealing wax serves for the handle.

Electrical Machines. — These may be made from old gramophone records, but if it is likely that the machine will be often used, circular glass plates varnished with shellac should be purchased and mounted.

Leyden Jars. — Cover large beakers inside and out with tinfoil, leaving a space of two inches at the top. A large piece of wood fitted across the top will hold the vertical wire and ball in place.

Induction Coil. — The construction of this is well known, but if it is desired to make one giving more than a half inch spark special care should be taken to insulate the secondary wire by winding it in flat sectional coils, each thoroughly saturated with paraffin wax. A rough check on size is given by reckoning at least one pound of wire for the secondary winding for each inch of spark.

Transformer. — This is a most useful piece of apparatus, as it can be used in many experiments in electricity — for charging batteries, working lamps in light experiments, demonstrating certain principles in the transmission of electricity, electric welding, and the use of high voltage currents. Stalloy laminations in the shape of a hollow square, one side of which can be removed, should be employed. These should be fixed in a small frame and tightly clamped together so that the magnetic circuit contains no appreciable air gap. Coils of various numbers of turns should be wound on fibre formers so that they may be slipped on to opposite arms of the Stalloy laminations. The teacher will experiment to find suitable numbers of turns on the winding — the greater the current it will have to carry the smaller will be the voltage across it. If the primary is fed with mains current a secondary coil brought out in loops to terminals at intervals may be made to yield voltages from 2 volts to 16 volts. Various windings are interchangeable by removing the cross-piece of the laminations. Much suitable electrical material can still be salvaged from 'junked' war apparatus.

Electrical Circuits

Electrical circuits can conveniently be shown by means of a demonstration board. A large drawing board is perforated with a number of holes to which various pieces of apparatus may be attached, and four pieces of copper strip each terminating and held with two terminals are fastened parallel to each side so that a gap between pairs of terminals is left at each corner. Switches, batteries, resistances, galvanometer, etc., may be connected to the terminals to close the gaps and form a circuit, and, in fact, the

demonstration board can easily be adapted to form a Wheatstone bridge. Standard resistances may be made by winding insulated Eureka wire on fibre formers, enclosing in test-tubes and sealing with Chatterton's compound. Insulated resistance wire may be wound non-inductively by doubling it into a loop before winding on the former.

Dynamos and motors may be made from old magnetos, and often an old car dynamo may be purchased for a few shillings. The powerful permanent magnets of magnetos may be used in making galvanometers of various types.

Obsolete telephone and telegraph apparatus may often be obtained from the post office authorities. This may be wired to form a small telephone exchange in the school, which will at once enable the pupils to gain experience in using the telephone and also to find out how it works. Simple sets for illustrating 'dialling' are also made by the post office.

'Heating spirals' may be bought quite cheaply from electrical supply shops and may be used to show how electricity is converted into heat for domestic purposes. Old electric irons, fires, vacuum cleaners, and wireless sets are always useful both for the material they contain, and also for showing the principles of their action and the way they are made.

Many manufacturers of electric wires and cables will supply samples, diagrams, and models showing how a house is wired. Every school should possess a distribution and fuse board for demonstration purposes. Boys and girls should have a thorough working knowledge of domestic wiring, fuses, switches, and circuits, including one with double switch and loop for controlling a light from two switches.

Stage lighting, with suitable switchboard fuses and dimmers, undertaken in connection with the school work in drama, will prove useful in conjunction with the practical teaching of electricity.

Other apparatus which may be made fairly simply:

- (1) Neon lighting set using old Ford car coil and 'trembler'.
- (2) Microphone.
- (3) Model generating station.
- (4) Electric clock for A.C. mains.

- (5) Electric 'slave' clocks.
- (6) Hot wire ammeter.
- (7) Electric trains, signals, safety devices, alarms.
- (8) Charging-set using a valve and transformer.

It is possible to go on multiplying instances but the ingenious and resourceful teacher will be able to think of many more examples, and will find that the sixpenny stores will yield dozens of articles which can be used for science purposes. The teacher will appreciate that with many things the best prove the cheapest, and it is unwise to spend money on very cheap edge tools or instruments of precision, which are to be permanent acquisitions. Actually an experiment gains by using the simplest and most common everyday things, where these are practical.

All science teachers should have some knowledge of handicrafts, and even though they may have the full co-operation of the crafts teachers both in metal and wood they should, if possible, have at their disposal a set of simple tools for metal and wood and supplement the use of these with a knowledge of the properties of various types of glasses, cements, wires, and indeed any materials or substances which can be used in science apparatus.

For further Reading

Science in Senior Schools. H.M.S.O.

This gives a particularly useful account of the requirements for science rooms and apparatus in 'Senior' schools, and a list of tools for work in science handicraft.

The Science Masters' Book (four volumes). Murray.

These present full instructions for making and using apparatus for teaching various branches of physics, chemistry, and biology at all stages. Some of the experiments are rather advanced.

School Laboratory Management. A. Sutcliffe. (Murray.)

Laboratory Workshop. Duckworth and Harries. (Bell.)

Laboratory Arts. G. H. Woollatt. (Longmans.)

Laboratory Manual of Glass Blowing. F. C. Frary. (McGraw.)

School Laboratory Fittings. Munby. (Bell.)

An Introduction to Laboratory Technique. Ansley. (Macmillan.)

Modern Glass Working and Laboratory Technique. Nokes. (Macmillan.)

The School Science Review (Murray), a periodical which, though intended primarily for work in grammar schools, contains articles which are invaluable to teachers of science in other fields.

The Teaching of Science in Secondary Schools (Murray, 1947), compiled by a joint committee of the Incorporated Association of Assistant Masters and the Science Masters' Association, contains much valuable material concerning the problems of science-teaching in grammar and 'public' schools. In particular, the sections on Laboratories, Examinations, First Aid in the Laboratory and The Science Teacher and the Law are particularly valuable, especially for teachers at the 'grammar school level'.

Tools and Materials for Science Handicraft

Tools

These tools are needed in the science room itself and are quite independent of the tools required in the manual training room.

Some items indeed are commonly not found in the latter.

1 Hammer, engineer's, ball pein, 1 lb. with handle.

1 „ „ cross pein, $\frac{1}{2}$ lb. with handle.

1 Rule, steel, 12", marked inches and cms.

1 Spanner, adjustable.

1 Try square, steel (ord. qual.), 4".

1 Callipers, 6", outside spring.

1 „ 6", inside spring.

1 Dividers, steel, 6".

1 Scriber.

1 Centre punch with fine point.

1 Cold chisel, flat, $\frac{1}{2}$ " \times 6".

1 „ „ cross cut, $\frac{1}{4}$ " \times 4".

1 Adjustable hack saw frame.

1 Doz. hack saws, 8", 32 teeth to the inch.

1 Breast drill to take up to $\frac{1}{2}$ ".

1 Set of twist drills, $\frac{1}{16}$ " to $\frac{1}{4}$ ", in 64ths.

1 Pliers, electricians.

- 1 Tinmen's snips, straight, 8".
- 1 " " bent, 6".
- 1 Electrician's screwdriver, 6".
- 1 " " " 3".
- 1 Set of stocks and dies with collets, Whitworth, $\frac{1}{8}$ ", $\frac{3}{16}$ ".
- 1 Set plug and taper taps, $\frac{1}{8}$ ", $\frac{3}{16}$ ", $\frac{1}{4}$ ", Whitworth, with tap wrench.
- 1 Set of stocks and dies, B.A. thread with collets, size 6, 4 and 2 B.A.
- 1 Set plug and taper taps, B.A., sizes 6, 4 and 2, with wrench.
- 1 File, 10", 3-square bast with second cut.
- 1 File, 8" half-round, second cut.
- Handles for previous two items.
- 1 Soldering iron, 2 oz.
- 1 " " 12 oz.
- 1 Collection small files with handles, round, square, half-round and flat, 5" size, second cut.
- 1 Carpenter's brace with ratchet, 10".
- 1 Set machine bits for wood, $\frac{1}{8}$ ", $\frac{1}{4}$ ", $\frac{9}{32}$ ", $\frac{1}{2}$ ".
- 1 " " " metal $\frac{1}{8}$ ", $\frac{1}{4}$ ", $\frac{9}{32}$ ", $\frac{3}{8}$ ".
- 1 Countersink bit, $\frac{3}{8}$ ".
- 1 Plane, smooth, 8" \times 1 $\frac{3}{4}$ ".
- 1 Wood chisel, $\frac{3}{4}$ ", with handle.
- 1 " " $\frac{1}{2}$ ", " "
- 1 Tenon saw, 12", iron back.
- 1 Washer cutter.

Materials

The raw materials which may be useful are so varied in character that it is not possible to make an exhaustive list.

3 paint brushes (small).

Copper wire, double cotton covered. Many pounds of various gauges. A school may easily use 28 lb. in a very short time at the outset. Gauges 24 and 28 are very useful but some thicker (4 lb. No. 18) and a little of thinner ($\frac{1}{4}$ lb. No. 36) will be found useful.

A small quantity ($\frac{1}{4}$ lb.) of silk-covered copper wire No. 38.

Nichrome wire, about $\frac{1}{2}$ lb. of No. 24 and $\frac{1}{4}$ lb. of No. 38.

Sheets of copper, zinc, aluminium and tin — about 1 lb. of each.
Copper tubing, $\frac{1}{2}$ ", 1" and 2" diameter. About 6 feet of each.
Iron, silver steel and brass rods, $\frac{1}{8}$ ", $\frac{1}{4}$ ", $\frac{3}{8}$ " and $\frac{1}{2}$ " diameter.

About 6 feet of each.

. Zinc rods, $\frac{1}{2}$ " diameter.

A large number of terminals.

Wood, oak or canary, $\frac{1}{4}$ ", $\frac{1}{2}$ " and $\frac{3}{4}$ " thick.

„ 3 ply and 5 ply.

1 lb. of beeswax.

4 oz. sealing wax.

4 oz. fuse wire, 5 amps.

5 lb. lead shot.

3 lb. paraffin wax.

A small piece (1 sq. ft.) rubber sheet.

Seccotine and Croid glue.

1 lb. shellac.

2 lb. solder.

60 ft. of flexible wire ('flex').

$\frac{1}{2}$ lb. of blue and of red enamel.

A tin of Brunswick black.

Wood dowelling to $\frac{5}{8}$ ".

Meccano parts. Cigarette tins.

Some Notes on Steps in Laboratory Glass Working

Cutting. Use of diamond and wheel cutters.

Do not press too hard, make the line in a single continuous movement. A little turpentine is helpful. Snap apart by gripping the glass on both sides and at one end of the scratch and give a pull rather than a bend to the glass.

Use of radial cutter for cutting circles,
or paste a circle of paper to the disc and make tangential scratches,
grinding finally to exact shape,
or make a circular scratch with several radial scratches.

Drilling. Drill between pieces of wood.

Use of copper or brass tube fixed to the drill and a mixture of carborundum powder (No. 100) and turpentine as drilling material. Turn the glass over when drilling is half completed.

Cutting Glass Tube and Rod

It is often useful to gum paper round the tube or rod. Start the cut with a file. Complete the crack with a heated glass bead or an electrically heated ring of resistance wire.

Thin rods and tubes will break without the above treatment (i.e. filing suffices).

Turpentine (or turpentine and camphor) assists the grinding processes.

Polishing glass with rouge preparation.

Use of lathe or wheel.

Glass Blowing

(1) Choice of glass. Use of same piece of glass (or similar type) for a single piece of work. Difficulties with different glasses.

(2) Experiments with blowpipe and Bunsen flames.

(3) Practice in rotating work necessary — even while blowing.

(4) Thin portions blow readily (often too readily) in flame; thick portions blow better out of flame.

(5) Annealing by cooling slowly, or holding in luminous gas flame.

(6) Drawing tubing instead of cutting it.

Some exercises: (a) various types of jets, (b) constricting bore of tube, (c) closing end of tube (use of charcoal block), (d) joining tubes — gently blowing before solidification, (e) joining tubes of unequal diameter, (f) blowing bulbs (melting sufficient glass into bulb), (g) right-angled junctions, Y-pieces, etc. — using fine flame, (h) an internal seal, (i) a filter-pump.

Notes on Soldering

(1) Necessity of clean surfaces.

(2) Use of fluxes. Zinc chloride (Killed spirits, Baker's fluid) — but not for small electrical work, fluxite, resin, tallow.

(3) Heating the 'iron'. Types of 'irons', electric irons. Tinning the iron.

(4) Use the bit at such a temperature that the solder is quite fluid. Try to avoid excess of solder.

(5) Use of soldering pastes, e.g. 'Britinol'.

(6) Grooved bit for soldering horizontal curves.

Solders

Material to be soldered	Composition of solder			Melting Point of Solder	Flux
	Lead	Tin	Bismuth		
Lead	1	1		188° C	Tallow
Brass, Copper, etc.	3	5		176° C	Zinc chloride, resin, fluxite
Zinc	3	5		176° C	Zinc chloride with free HCL
Pewter	2	1	2	113° C	Tallow
Iron	2	5		170° C	Sal ammon- iac solution

A First Aid Outfit for the Laboratory

Forceps	Burn dressing (gauze)
Needles	Tannic acid jelly
Safety-pins	Sulphonamide cream
Scissors	Vaseline
Camel-hair brush	Mustard
Spoon	Salt
Eye bath and dropper	Sal volatile
Triangular bandages	Olive oil
Elastoplast bandage	Smelling salts
Elastoplast dressing	Tincture of iodine
Medicated gauze	T.C.P. or other antiseptic
Cottonwool	1% acetic acid solution
Fresh lime water	8% sodium bicarbonate solution
Clinical thermometer	

Experiments on Explosives in Schools

Board of Education (Administrative Memorandum, No. 167,
July 5th, 1937)

An explosion recently occurred during a science lesson in a senior school whereby the master received serious injuries.

The experiment in progress was the making of a bomb to be exploded in the playground. Powdered chlorate of potash and antimony sulphide had been mixed in an envelope; red amorphous phosphorus was then added, the explosion occurring when the contents of the envelope were stirred with a piece of school chalk.

This followed a series of experiments on matches and explosives taken from a textbook on Science, the issue of which has since been suspended by the publishers as a result of representations made by the Home Office. Among the suggestions for experiments on explosives made in this book were:

(1) The making of gunpowder in small quantities for experimental purposes; this, while not illegal, is strongly deprecated by the Home Office.

(2) Mixing phosphorus and chlorate of potash.

(3) Mixing sulphur and chlorate of potash.

Both of these have been made illegal by Order in Council on account of the extremely sensitive and violently explosive character of these mixtures.

The Home Office has drawn the Board's attention to the fact that chemical sets for children frequently include chlorate of potash, sulphur and phosphorus, and that children's magazines often contained detailed instructions for the making of fireworks, an unlawful act. The Home Office also states that, contrary to the usual belief, red phosphorus need not be contaminated with yellow for it to explode when mixed with chlorate of potash.

CHAPTER XIII

SCIENCE LIBRARIES

IN the Board of Education Pamphlet No. 89, *Science in Senior Schools*, the need for suitable books for general science reading is stressed. It is suggested that a collection of at least two to three hundred books should be provided. To these a number of periodicals dealing with science, model engineering, photography, discoveries, and other hobbies of various types, including those related to biology, should be added. In the case of the majority of children leaving school it is inevitable that later interest in science is largely dependent on suitable reading.

Even where suitable books are provided there still remains the necessity of guiding children in the choice of books or suitable passages. The scientific romances of Jules Verne, H. G. Wells, Austin Freeman, and others are often found on the shelves of school libraries and are more properly kept in the fiction section, but the child should be encouraged to read them critically. In fact, it is a useful and interesting exercise for a child to detect the good and bad science in such works as *Twenty Thousand Leagues under the Sea*, and *A Trip to the Moon*.

The real backbone of the Science Library should be books of reference both for teacher and scholar, in addition to a number of science reading books apart from textbooks. The inquiring child should be directed to suitable sources of information so that after a time he will know how to use the library. Most public libraries have good science sections, but some of the best books on applied science are to be found in other sections such as 'Useful Arts', and it is advisable to give some instruction to prepare for later systematic reading of books from lending libraries, and also the use of reference departments for obtaining detailed information on any subject. In the following pages we give a list of books, most of which deal with particular subjects.

THE following list of books is by no means exhaustive; some may be read by school children without further explanation and others are for

reference purposes for both child and teacher. At the time of writing this edition some are only available in libraries.

Nature Study

- Living Things for Lively Youngsters. *Rowland. Cassell.*
 More Living Things for Lively Youngsters. *Rowland. Cassell.*
 Animal Ingenuity. *Ealand. Seeley.*
 The Romance of the Animal World. *Selous. Seeley.*
 The Romance of Insect Life. *Selous. Seeley.*
 The Romance of Plant Life. *Scott Elliot. Seeley.*
 The Romance of Bird Life. *Lea. Seeley.*
 The Romance of Animal Arts and Crafts. *Lea. Seeley.*
 The Romance of the Microscope. *Ealand. Seeley.*
 The Wonders of Bird Life. *Lea. Seeley.*
 The Wonders of the Plant World. *Scott Elliot. Seeley.*
 The Wonders of Animal Ingenuity. *Coupin. Seeley.*
 The Wonders of the Insect World. *Selous. Seeley.*
 Botany of To-day. *Scott Elliot. Seeley.*
 Nature Studies and Fairy Tales. *Dodd. Nelson.*
 The Book of Nature Study (six volumes). *Farmer. Caxton.*
 British Birds. *Thorburn. Longmans.*
 A Bird Book for the Pocket. *Sanders. O.U.P.*
 How to Know British Birds. *Joy. Witherby.*
 British Birds. *Kirkman and Jourdain. Jack.*
 Name this Bird. *Daglish. Dent.*
 The Natural History of Selborne. *White. Blackwell: Dent: Pelican.*
 The Miracle of Life. *Various authors. Odhams.*
 The Story of Living Things and their Evolution. *Mayo. Waverley.*
 The Zoological Gardens. *Gleeson. Low.*
 The Young People's Microscope Book. *Sedgwick. Sharp.*
 The Beginner's Guide to the Microscope. *Heath. Marshall.*
 The Microscope Shown to the Children. *Ellison Hawks. Black.*
 Nature Rambles (four volumes). *Step. Warne.*
 The Teachers' Book of Nature Study (two volumes). *Evans Bros.*
 The Outline of Natural History. *Thomson. Newnes.*
 Fresh Water Aquaria. *Bateman. Bazaar Exchange & Mart.*
 Animal Mysteries. *Boulenger. Duckworth.*
 Animal Ways. *Boulenger. Ward Lock.*
 Animals in the Wild and in Captivity. *Boulenger. Ward Lock.*
 The Seas. *Russell and Yonge. Ward Lock.*
 British Nature Book. *Sedgwick. Nelson.*

- The Romance of the Seasons. *Duncan*. Chapman.
 The Fairy Land of Living Things. *Kearton*. Cassell.
 Cassell's Natural History (six volumes). *Duncan*. Cassell.
 The Country Day by Day. *Wood*. Cassell.
 Eyes and No Eyes. *Buckley*. Cassell.
 The Beauties of Nature. *Avebury*. Methuen.
 The Children's Life of the Bee. *Maeterlinck*. Unwin.
 The Outdoor Year. *Claxton*. Blackie.
 Animal Heroes. *Seton*. Constable.
 Our Secret Friends and Foes. *Frankland*. S.P.C.K.
 The Wonder Book of Why and What. *Golding*. Ward Lock.
 The Wonder Book of Wonders. *Golding*. Ward Lock.
 The Wonder Book of Nature. *Golding*. Ward Lock.
 The Romance of the Mighty Deep. *Giberne*. Seeley.
 The Romance of the World's Fisheries. *Wright*. Seeley.
 Everyday Doings of Insects. *Cheesman*. Harrap.
 Garden and Playground Nature Study. *Feasey*. Pitman.
 The Junior Gardener. *Price*. Dent.
 Vegetables and their Cultivation. *Sanders*. Collingridge.
 Glasshouses and the Propagation of Plants. *Fletcher*. Benn Bros.
 The Gardeners' Year. *Capek*. Unwin.

(See also Cassell's Gardening Series.)

- The Romance of the Seasons. *Duncan*. Chapman.
 Nature Rambles in London. *Hall*. Hodder & Stoughton.
 British Woodland Trees. *Edlin*. Batsford.
 Good Farming. *Fishwick*. E.U.P.
 Ley Farming. *Stapledon and Davies*. Pelican.
 Keeping Rabbits and Poultry. *Thompson and Goodchild*. Pelican.
 Beekeeping. Bulletin No. 9. Min. of Ag. & Fish. H.M.S.O.
 Water in Nature. *Finch and Hawks*. Nelson.
 See also the following Series by *Duncan*, O.U.P.

Wonders of Plant Life.

Wonders of Insect Life.

Wonders of the Sea.

Young Naturalist Series. Brockhampton Press.

The Soil. *Hall*. Macmillan.

Golden Nature Readers. *Knight*. University of London Press.

Trees in Britain. *Brimble*. Macmillan.

Flowers in Britain. *Brimble*. Macmillan.

The Floral Year. *Brimble*. Macmillan.

A Guide to Bird Watching. *Hickey*. Oxford University Press.

The World of Living Things. *Sparrow*. Vawser & Wiles.
 The Ocean. *Ommanny*. Oxford University Press.
 The Young Bird Watchers. *Hillstead*. Faber & Faber.
 Flower and Leaf. *Armitage*. Gifford.
 Life in Pond and Stream. *Morse*. Oxford University Press.
 Children as Naturalists. *Hutchinson*. Allen & Unwin.
 Britain's Structure and Scenery. *Dudley Stamp*. Collins.

Biology

(See also under *Nature Study*)

Living Things. *Palmer*. Allen & Unwin.
 The Animal's World. *Mackinnon*. Bell.
 Elementary Studies in Plant Life. *Fritsch and Salisbury*. Bell.
 Animals in the Making. *Dell*. Bell.
 Living Things. *Bailey-Churchill*. Bell.
 The Science of Life. *Wells and Huxley*. Cassell.
 Animal Biology. *Haldane and Huxley*. O.U.P.
 Microbes and Ultra Microbes. *Gardner*. Methuen.
 Botany of To-day. *Scott Elliot*. Seeley.
 Biology for Everyman. *Thomson*. Dent.
 Everyday Biology. *Thomson*. Hodder & Stoughton.
 The Origin of Species. *Darwin*. Dent.
 The Voyage of the Beagle. *Darwin*. Dent.
 Extinct Monsters and Creatures of Other Days. *Hutchinson*. Chapman
 & Hall.
 Life and Evolution. *Headley*. Duckworth.
 Rural Science. *Mason*. McDougall.
 Microbes by the Million. *Nicol*. Pelican.
 Cine-Biology. *Durden, Field and Smith*. Pelican.
 Hydroponics. *Hilyer*. Pelican.
 School Course in Biology. *Brimble*. Macmillan.
 Teach Yourself Biology. *Phillips and Cox*. E.U.P.
 The Personality of Animals. *Munro Fox*. Pelican.
 Biological Control of Insects. *Nicol*. Pelican.
 The Advance of the Fungi. *Large*. Cape.
 Beyond the Microscope. *Smith*. Pelican.
 Simple Experiments in Biology. *Bibby*. Heinemann.
 Practical Plant Ecology. *Tansley*. Allen & Unwin.
 Microbe Hunters. *De Kruif*. Cape.
 The Fight for Life. *De Kruif*. Cape.
 Men Against Death. *De Kruif*. Cape.

Heredity. *Adams. Heffer.*

A Picture Book on Evolution. *Beadnell. Watts.*

An Introduction to Social Biology. *Dale. Heinemann.*

Heredity and Environment. *Maguinness. Nelson.*

The Teaching of Social Biology. *Norwood and Sumner. B.S.H.C.*

The Living Organism. *Knowles. Harrap.*

Plant Ecology and the School. *Tansley and Price Evans. Allen & Unwin.*

Biology in the School. *Peacock. Heinemann.*

Biological Models and Apparatus. *Brittain. Murray.*

Life on the Sea-Shore. *Eunion. Oxford University Press.*

Hygiene, Physiology, etc.

Man, Microbe and Malady. *Drew. Pelican.*

Living Machinery. *Hill (A. V.). Bell.*

Human Physiology. *Hill (L.). Macmillan.*

Engines of the Human Body. *Keith. Williams & Norgate.*

Medical Science of To-day. *Evans. Seeley.*

Readable Physiology and Hygiene. *Campbell. Bell.*

Biology and Human Welfare. *Peabody and Hunt. Macmillan.*

Civic Biology. *Hodge and Dawson. Ginn.*

The Conquest of Disease. *Masters. Lane.*

Health and the Future. *Bourne. Pelican.*

Sex Education. *Bibby. Macmillan.*

New Biology. *Various Authors. Pelican.*

Beyond the Microscope. *Smith. Pelican.*

How You are Made. *Williams-Ellis. Black.*

Battle for Health. *Taylor. Nicholson & Watson.*

Man and Other Living Things. *Knowles. Harrap.*

Experimental Human Biology. *Bibby. Heinemann.*

The Body and its Health. *Cullis and Bond. Allen & Unwin.*

How the Body Works. *Michaelis. Longmans.*

The Miracle of the Human Body. *Roberts. Odhams.*

The House: A Machine for Living In. *Bertram. Black.*

Hygiene and Health Education. *Davies. Longmans.*

The Enemy Under the Microscope. *Kuznetsova. Hutchinson.*

Man, Microbe and Malady. *Drew. Pelican.*

Genetics. *Kalmus and Crump. Pelican.*

The Stuff We're Made of. *Kermack and Eggleton. Oxford University Press.*

Feeding the Human Family. *Le Gros Clark. Sigma.*

Mankind So Far (Anthropology). *Howells. Sigma.*

General Physics, Heat, Mechanics, etc.

- Engines. *Andrade*. Bell.
 The Mechanism of Nature. *Andrade*. Bell.
 Concerning the Nature of Things. *Bragg*. Bell.
 The Romance of Modern Engineering. *Williams*. Seeley.
 The Wonders of Mechanical Ingenuity. *Williams*. Seeley.
 The Romance of Modern Invention. *Williams*. Seeley.
 Engineering of To-day. *Corbin*. Seeley.
 Mechanical Inventions of To-day. *Corbin*. Seeley.
 Aircraft of To-day. *Turner*. Seeley.
 Marvels of the Ship. *Chatterton*. Seeley.
 Railways. *Williams*. Seeley.
 The Romance of Submarine Engineering. *Corbin*. Seeley.
 Readable Relativity. *Durell*. Bell.
 Readable School of Mechanics. *Fawdry*. Bell.
 Joule and the Study of Energy. *Wood*. Bell.
 Conquests of Engineering. *Hall*. Blackie.
 Wonders of Transport. *Hall*. Blackie.
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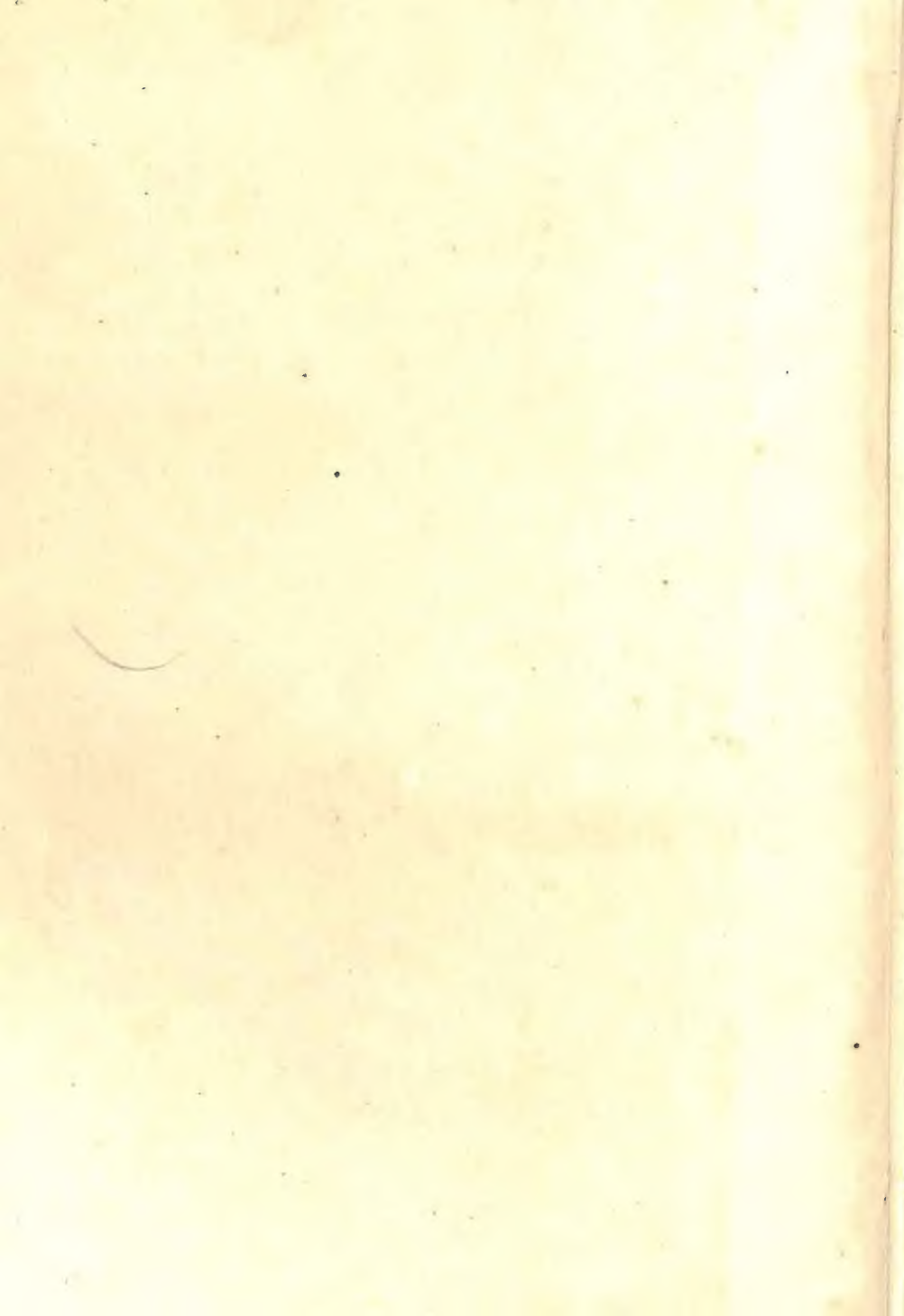
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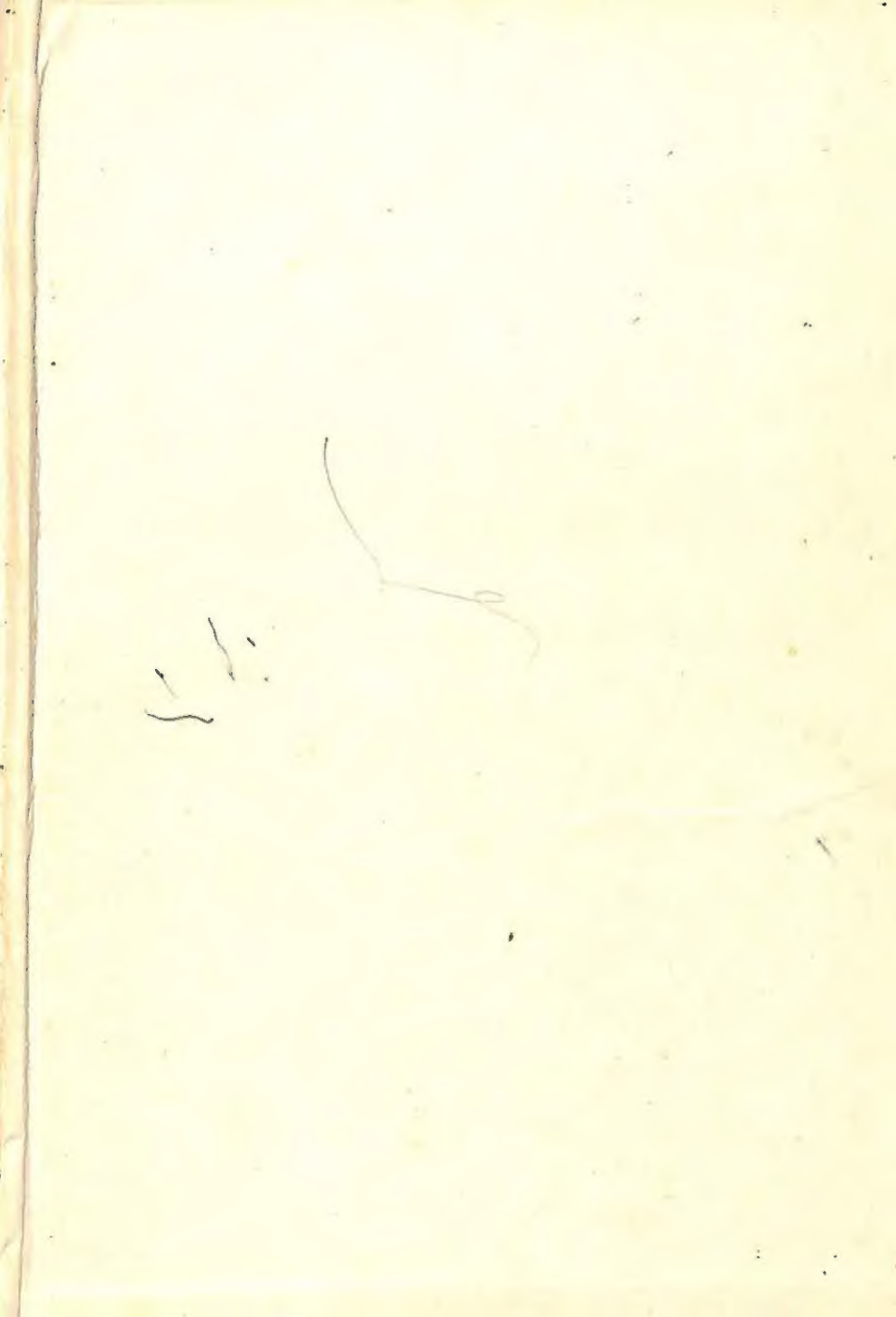
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